ENGINEERING
FOR FOREST RANGERS
IN TROPICAL COUNTRIES

I. Carting teak with buffaloes across a temporary forest bridge.

ENGINEERING
FOR FOREST RANGERS
IN TROPICAL COUNTRIES

WITH SPECIAL REFERENCE TO

BURMA

BY

A. H. LLOYD

M.C., M.A.

Indian Forest Service

Lecturer in Forest Engineering,

Imperial Forestry Institute, Oxford

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FOREWORD

THIS Manual of Forest Engineering, by Mr. A. H. Lloyd, Deputy Conservator of Forests and Director of the Burma Forest School, has been written by him in response to a crying need for a simple text-book on the subject. This need was felt generally throughout the Forest Service, and especially by the Burma Forest School, the main purpose of which is to give a sound practical training to the executive staff. The main desideratum of the text-book was that it should set forth the elementary principles of engineering in their application to forest work in a concise, practical, and common-sense manner, and in simple language. Mr. Lloyd has succeeded in fulfilling these requirements in a truly admirable manner. His book is concise, simple, practical, and sound. I am confident that its range of utility will not be restricted to the Forest Department in Burma for which it was primarily written. Its conciseness and simplicity should appeal not only to all agencies working timber in Burma, but to all those concerned with education and forest management or exploitation in the tropics.

H. W. A. WATSON
Chief Conservator of Forests

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PREFACE

A Forest Ranger has frequently to undertake engineering work in the forests which under other circumstances would be entrusted only to a trained engineer. This book is an attempt to supply, to some extent, the urgent demand for a manual dealing with this kind of forest work in tropical countries in a simple way which can be understood by untrained men. It is primarily designed to serve as a Manual in Forest Engineering for students at the Burma Forest School, and deals chiefly with materials and methods actually used in Burma. It is hoped, however, that the book may also be of use to newly-joined forest assistants and others who, with no previous experience, may have to carry out work in countries where conditions are similar to those in Burma and in places where expert advice and help are not available.

Most forest engineering is necessarily of a simple character, but it must be carried out on sound lines if the work is to be done economically. Forest Rangers cannot be given a long course of training in the elementary principles of engineering, hence it has frequently been found necessary in this manual to lay down rules dogmatically rather than to discuss the principles involved. Descriptions of simple methods have been given in considerable detail, and some of the remarks in this book may appear obvious and unnecessary, but they have been included because of observed mistakes. Technical terms have been avoided, except where they are considered necessary for a clear explanation of the subject, and an attempt has been made to write as simply as possible.

The manual has to deal with many different branches of engineering and the treatment of each subject is necessarily very limited and elementary. For further information on any particular subject the reader is advised to refer to one of the more comprehensive treatises indicated in the bibliography on p. 222.

Roads and buildings form the greater part of the engineering work carried out by the Forest Department. Hence three chapters of this manual have been devoted to buildings and materials of construction, and six chapters to forest roads and road-bridges. The remaining chapters deal with the transport of timber, the water-supply, and miscellaneous engineering works.

The photographic illustrations have been taken chiefly in the Pyinmana Forest Division, Upper Burma, where arrangements for the photographs of timber extraction were kindly made by the Bombay Burma Trading Corporation and Messrs. Macgregor & Co. The drawings have been prepared by students at the Burma Forest School, chiefly from sketches of actual works seen on tour.

Thanks are due to Major E. H. Clarke, R.E., Commandant, Burma Sappers and Miners, and to Mr. C. H. Philipp, Conservator of Forests, for reading the proofs and offering many useful suggestions. Mr. A. Long, Instructor, Burma Forest School, has been of great assistance in preparing many of the photographs; and Mr. W. B. King, Forest Manager, Messrs. Steel Bros., has kindly revised the chapter on the transport of timber.

The book is a first effort. Standard text-books on Civil Engineering have been consulted where possible, but for most of the work described in this manual the writer has had to depend chiefly upon his own limited practical experience in Burma and Canada, and in the Royal Engineers during the war. The inadequacy of this experience is fully realized, and it is hoped that Divisional Forest Officers and others will come forward with criticisms and suggestions to enable a better and more complete edition to be published at a later date.

A. H. L.

PYINMANA, BURMA,
1 March 1928.

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I

MATERIALS USED IN FOREST ENGINEERING

ENGINEERING has been defined as the directing of the great resources of nature for the use and convenience of man. Thus it covers a very wide range of work and includes many different branches such as mechanical, electrical, mining and civil engineering. The work with which a Forest Ranger has to deal may be termed forest engineering and consists chiefly in the construction and maintenance of forest roads, bridges and buildings, and the extraction and transport of timber.

Before undertaking any definite piece of engineering work a knowledge of the materials to be used is essential, hence we shall begin by briefly considering some of these materials.

1. SELECTION OF MATERIALS

For the construction of forest buildings and other works, local products such as timber, bamboo, and stone, which are available in the forests near at hand, are used in preference to materials from outside. Owing to the high cost of transport to the site it is not usually economical to purchase outside materials, even if they are better than the local products. For instance, practically all forest bridges are built of timber instead of masonry or steel, although these latter would be much more durable.

The difficulty of getting skilled labour is another factor which influences the choice of materials. Local villagers can usually be found who are capable of erecting rough timber and bamboo structures, but skilled masons or builders can seldom be induced to undertake forest work except at unduly high rates.

Climatic and other local conditions may also affect the selection. Materials which have proved successful in a dry district may be quite unsuitable for a locality where the annual rainfall is heavy. Local conditions must therefore be studied carefully before making any attempt to introduce new materials or new methods into a district, and there is usually a good reason for local customs.

Prices of materials and the cost of labour vary greatly from year to year and in different districts. In the few cases where costs are quoted in this book they are intended to be used only as a very rough guide, and current local prices must always be carefully ascertained before any estimates for work are submitted.

The following brief descriptions of materials which are commonly

used in forest work may show the chief points to look for, but a useful knowledge of these materials can be gained only by practical experience.

2. TIMBER

Wood suitable for building or other engineering purposes is usually called timber. When it forms part of a living tree it is called standing timber; after it has been sawn into beams, planks, scantling, battens, or other forms, it is called converted timber. For the conversion and seasoning of timber and for a comparison of the strengths of various kinds of timber reference should be made to books on Forest Utilization. Here we shall only deal briefly with the general qualities and characteristics of structural timber.

Characteristics of good timber. The timber should be heavy in weight, with a smooth and hard appearance at a freshly cut surface; a dull chalky appearance is a sure sign of bad timber. It should also be regular and even in growth as shown by the annual rings. The wood should be straight in fibre, close-grained, and free from large or dead knots, shakes, or any signs of decay. In coloured woods, darkness of colour is said to be a sign of strength and durability, but the colour must also be uniform throughout and not in patches. In the case of timber used for beams or girders in roofs or bridges, it is particularly necessary that the grain of the wood should be straight. Engineers often specify that if a crossgrain is present near the centre of a beam the slope of the grain shall not exceed a certain degree.

The rejection of timber for defects will naturally depend upon the type of structure for which the timber is required. In timber for bridges or for first-class buildings, only small knots which are sound and which remain tight in the wood after conversion should be permitted, and no knots should be larger than one-fourth of the thickness of the timber. A beam containing a cluster of knots in any one part should be rejected, and the maximum diameter allowed for single knots in beams is usually 3 to 4 inches if near the ends of a beam, and $1\frac{1}{2}$ to 2 inches if near the middle. Similar allowances are made for insect-borer holes, but no timber which is suspected of containing active borers must on any account be used.

Sapwood is much less durable than heartwood, and is also more liable to damage by insects, hence for permanent structures heartwood alone should be used. Converted timber containing sapwood should never be used for important work, and in the case of round timber for posts or girders all sapwood should be trimmed off before the timber is passed for use. The proportion of sapwood to heartwood in a log varies from 12 to 60 per cent. according to the different

species of timber. In the case of most tropical woods the sapwood can easily be distinguished as it is generally much lighter in colour than the heartwood.

The timber produced from a newly felled tree is called green timber, and is full of sap. If this sap is not expelled by drying or seasoning the wood is liable to decay rapidly, and it may also shrink and warp, or develop cracks after it has been placed in position. Newly felled timber should therefore not be used for general construction, although in emergencies and for temporary work the use of such timber is often unavoidable. With proper management, it should usually be possible to arrange for the felling and conversion of sufficient timber for ordinary purposes at least a year before it is required for use. Most tropical timbers are best converted as soon as possible after felling and the converted timber then seasoned, but a few species are best seasoned in the log. For fine carpentry work and where accurate joints are required the timber must always be thoroughly seasoned, either artificially in kilns, or naturally by storage in properly stacked piles.

Causes of decay in timber. Timber will not usually decay if it can be kept constantly dry and placed where air can get to it freely. Also if timber has to be kept continuously under water it is weakened and may become brittle but does not generally decay, and some kinds of timber such as *kathit* (*Erythrina, sp.*) and *letpan* (*Bombax malabaricum*) are more durable under water than when exposed to the air.

Timber decays most rapidly if it is placed in positions where it is alternately wet and dry, or in contact with damp earth or masonry. Posts are therefore most liable to decay at the surface of the ground or just below it, and when applying preservatives this part should receive special attention. Lime is specially destructive to timber, hence beams should not be placed in direct contact with lime mortar.

There are two main causes of decay in timber, which are known as dry rot and wet rot.

Dry rot is a fungus which usually attacks timber that is totally enclosed from the air. The fungus grows very rapidly and will quickly spread to surrounding timber. Sunlight and fresh air kill the dry-rot fungus, and therefore the best protection is to ensure a free circulation of air round the timber wherever possible. Wooden flooring should never be laid directly on the ground, and timber should always be stacked in such a way that air can get freely to every part of the stack. In buildings a clear air space should always be left at the end of beams.

Wet rot may occur by internal decay, when the tree is standing, or in logs which have been left lying on the ground or floating in water. Prevention of wet rot can be effected first by using only seasoned timber, and then by keeping out further moisture by charring, tarring, or painting. It is very important to see that the wood is seasoned or dry before paint is applied, as otherwise the paint would actually hasten decay by filling up the outer pores and confining the moisture.

White ants. In the tropics timber is especially liable to damage from the attacks of insects, particularly white ants. No single method gives permanent protection from these insects. Teak (*Tectona grandis*) is rarely attacked by white ants and certain timbers, such as *sagowa* (*Michelia Champaca*) are impregnated naturally with acid or bitter salts, which protects them from attack. Treating the wood with preservatives, such as creosote, and isolating it from the ground are the two most common methods of protection.

There are several kinds of white ants, or termites, but most of the damage done to timber in the tropics is caused by the subterranean species. These insects require access to damp earth, and if this source of moisture is cut off they cannot exist. Wooden buildings in the Malay States and other tropical countries are often protected by resting the lower ends of the house-posts in iron sockets or cups, which are supported on brick or concrete plinths about 2 feet in height. These sockets are kept filled with earth-oil containing a small quantity of arsenic, so that white ants cannot ascend beyond them, and the earth-oil also protects the timber from rot.

The nests and burrows of white ants should always be dug up and destroyed if in the vicinity of wooden buildings and bridges. The queen ant, which has the appearance of a thick white grub, and is about 2 to 3 inches long, should be searched for and destroyed when digging out a nest.

3. PRESERVATION OF TIMBER

There are many different methods used for the protection of timber from insect attack and from decay. Some of these, such as painting and oiling, chiefly depend on providing a waterproof covering to the timber; while other preservatives, such as Creosote and Solignum, depend on impregnating the timber with certain antiseptic salts.

Before any preservative treatment is started all bark must be removed from the timber. The inner bark prevents the penetration of the preservative, and, also, it is useless to apply preservative to

the outside bark which soon falls away. The timber should also be dry or seasoned, for if it still contains moisture in its pores and cavities the antiseptics will not be absorbed, and there are other reasons for drying the timber as will be seen below.

Many processes have been invented for increasing the penetration of the preservatives, but for the small quantity of timber used in the forest structures dealt with in this book, the preservatives are usually simply applied with a brush, giving the wood one or more coats either with the cold solution or after it has been heated.

Charring. Charring the timber is one of the earliest methods of protection known and was used for the posts of the palaces built by the Burmese kings many centuries ago. The ends of posts and piles should always be either charred or tarred before being put into the ground. Charring is done by heating the butt end of the post over a steady wood fire and turning it round until all surfaces are thoroughly charred to a depth of about $\frac{1}{2}$ inch. Water should then be thrown on to quench the fire. The wood must first be seasoned or fairly dry and then the heating helps to drive out the remaining moisture in the wood. If green timber is charred the moisture in the centre of the timber cannot escape, and attacks of dry rot and decay are encouraged, so the charring may then do more harm than good.

Charring takes much time and labour, and can be done only on a small scale. Also if the charring is too deep it weakens the timber. Tarring is therefore generally considered to be a better method.

Tarring. As already mentioned, only seasoned or dry timber should be tarred. The tar should always be applied while hot, with a brush. The heating makes the liquid thin and enables it to penetrate the timber. Tarring should never be carried out in damp or cold weather. It is important to see that the tar is brushed well into all joints and cracks in the timber. The tops of posts and the ends of girders and beams should receive an extra coating after any large cracks or holes have been filled with putty or with pitch.

One gallon of tar will cover about 100 square feet of timber. The weight of a gallon of tar is about $10\frac{1}{4}$ pounds, and an ordinary drum of tar contains 5 gallons. Payment is made per 100 square feet, and the rate varies according to the number of coats used. The preserving action of tar largely depends upon the amount of creosote it contains. Care should be taken to purchase good quality tar from a reliable firm, as some of the tar sold in the bazaars is almost useless. Timber treated with tar is very inflammable and must be well protected from fire.

Creosoting. Creosoting is expensive but has proved to be the

most generally successful of the many processes which have yet been adopted for preserving timber from decay by treating it with antiseptic substances. Creosote does not get washed out by water and it protects the timber not only against dry and wet rot but also against white ants and other insects. It is commonly used for railway sleepers and telegraph poles. The timber to be treated may be soaked in creosote in open tanks under a special system of successive heating and cooling, but a much better result is obtained from forced impregnation. Specially constructed cylinders and suction pumps are necessary for this process, in which much of the moisture is first expelled from the wood to be treated, and the creosote is then forced into the pores under pressure. In America, where soft-woods are more generally used than in the tropics, hot creosote is applied with a brush to telephone poles before they are erected. The creosote is heated in an iron pot to a temperature of about 150° F., and two coats are applied at an interval of twenty-four hours. Only the lower ends of the posts are treated, from the bottom up to a point at least 18 inches above the ground.

True creosote is obtained from wood, but the common creosote used for timber preservation is obtained from coal-tar. Creosote is often diluted with crude oil up to 50 per cent. This mixture is cheaper to use than pure creosote; it gives practically the same protection, and when heated it has been found to penetrate more deeply into the timber. Pitch and coal-tar are also often mixed with creosote. The amount of creosote required depends to a great extent on the kind of timber treated. Soft-woods will absorb more than twice the quantity that hard-woods will absorb under the same conditions. Owing to the high cost of creosote it is not often used for forest work except where plant is locally available for proper impregnation.

Solignum is a preservative now commonly used in the tropics for doors, window-frames, and other woodwork. It has been proved to give a very effective protection against white ants. Its composition is a trade secret, but it contains certain creosote oils. It is usually coloured with pigments of various shades to make the treated timber attractive in appearance, and is often used as a stain both for interior and outdoor work. The timber to be treated must first be thoroughly dry, and the solution is applied with a wire brush, preferably after being heated, but it is sometimes applied cold. Solignum does not increase the inflammability of the wood and is suitable for use in places where the appearance and odour of coal-tar or of ordinary creosote would be objectionable. One gallon of Solignum is sufficient for about 350 to 400 square feet of timber.

Atlas solution. This is another trade secret preservative. It is highly poisonous, as it contains arsenic, and should be handled with care. A solution of 15 to 20 per cent. of Atlas is often used for the treatment of railway sleepers and constructional timber, and it is also useful as a disinfectant and as a weed-killer. A dilute solution of Atlas has been used at the Burma Forest School for some years to mark out the football ground, and after a single application of the solution the lines of dead grass remain clearly defined for the whole season. Atlas is also very useful for the preservation of game trophies.

Paint. Paint is a very effective and useful preservative for woodwork which is exposed to the weather and greatly improves the appearance of a building, but it is very expensive, and is not often used by the Forest Department except for offices and other buildings in head-quarters. Paint is usually purchased ready mixed in tins, and if obtained from a reliable firm this is better than buying the ingredients separately. In many cases an additional quantity of some solvent such as spirits of turpentine is needed to make the paint work more freely. Only just sufficient solvent should be added to make the paint run readily with the brush, as if used in excess it reduces the durability, especially in the case of outdoor work. The application of paint requires considerable care if the paint is to be used to the best advantage, and a specification for painting should include:

(*a*) Number of coats: three coats on all timber exposed to the weather and two coats inside a building.

(*b*) Cleaning. The surface of the wood which is to be painted must be thoroughly dry, clean and smooth, and free from dust. Large knots should be first treated with red lead and glue size or with quicklime.

(*c*) A priming coat of white and red lead in linseed oil should be first applied, after which all cracks and knot-holes must be stopped with putty. The heads of all nails should be punched in below the surface and the holes then filled with putty.

(*d*) Paint should be laid on evenly, and each coat must be allowed to dry thoroughly before the next is applied.

Payment is usually based on a fixed rate per 100 square feet, according to the quality of the paint and the number of coats.

Varnish. Varnish is a solution of resin in oil, turpentine, or alcohol. It is used to brighten and protect painted surfaces, and is also often applied to unpainted wood, as in the case of furniture and interior woodwork in houses. Camp furniture will last longer and remain cleaner if it is varnished. Woodwork requires special preparation before varnishing, and in contracts for the varnishing

of new woodwork it should be speeified that the surface to be varnished should first be made perfeetly smooth with sandpaper or pumice stone, and that the wood should be 'stopped' with hot glue size in order to elose up the pores, and the surface then sand-papered again. One pound of glue makes one gallon of size. The varnish should be applied in very thin coats with special fine-haired varnishing brushes. Two eoats are usually sufficient. Payment is made at a fixed rate per 100 square feet, as for paint. A pint of varnish should cover 144 square feet of surfaee with one eoat.

Varnishes may be roughly classified as oil varnish, turpentine varnish, or spirit varnish, according to the solvent used, and they are generally ealled by the name of the gum or resin dissolved in them. Oil varnishes eontaining eopal or amber are the best for general use. They are more expensive than turpentine varnishes, but the latter are useless for outdoor work.

Oiling. Oiling is mueh cheaper than painting or varnishing. It has no antiseptic action like creosote, but it provides a waterproof surfaee to timber and keeps it dry. All unpainted woodwork not exposed to the weather should be oiled at least every two years, and exposed woodwork every year.

Crude earth-oil is commonly used for oiling the woodwork, posts, and bamboo mat-walling in forest buildings. It should be heated until it flows freely, and oiling should always be carried out during the hot weather. Red oehre is often mixed with the oil to give it a pleasing colour.

When posts are being oiled or tarred the surrounding soil should be removed to a depth of at least 18 inches, and the part of the post thus exposed should be treated very thoroughly, as this is the part most liable to decay. If sand is spread round the posts it is said to give additional protection from white ants.

Earth-oil is also used for the preservation of roof shingles. The shingles should be dipped in boiling oil, but must be perfectly dry before being put into the oil. The bundles of shingles must be opened up so that all surfaces are exposed. A four-gallon drum of oil is suffieient for one thousand hard-wood shingles: a little water is generally put in the receptaele below the oil to prevent the bottom from burning. A mixture of ereosote and earth-oil is better than pure oil.

Linseed oil is used for oiling doors and window-frames and other woodwork where earth-oil is not suitable. It is much more expensive than earth-oil, but is more durable. A eommon mixture is: 3 lb. double-boiled linseed oil, 1 lb. turpentine, 1 lb. beeswax. The oil and the wax should be heated in a vessel over a slow fire until the

wax is melted. After the mixture has cooled the turpentine may be added, and the mixture is then applied in two coats. In Burma linseed oil is frequently used pure without the beeswax.

Pure kerosene oil or paraffin is very effective against white ants and soaks well into the wood, but is only useful as a temporary measure.

Putty. Putty is used for fixing panes of glass in windows, and also for filling up holes and cracks in timber. It is composed of white chalk reduced to a very fine powder, called whiting, and boiled linseed oil. The whiting is mixed with the linseed oil into a stiff paste, which is then thoroughly kneaded. It should be mixed the day before it is required for use, as if it is kept for any length of time it becomes dry and hard, and must then be heated and mixed up again with fresh oil before it can be used. Putty is not usually satisfactory for rough buildings in tropical countries as it soon tends to crack and fall out, and narrow strips of wood or metal are now commonly used instead of putty for glazing windows.

Pitch. Pitch is a black shiny resinous substance obtained from the distillation of tar. It is chiefly used for caulking boats. The joints are first filled with hemp, and the pitch is then applied hot in a melted condition, and sets hard when cold.

Local materials can usually be obtained in the tropics which answer the purposes of putty and pitch. For caulking boats in Burma a substance called *indwe*, which is obtained from the *In* tree (*Dipterocarpus tuberculatus*), is generally used. A plastic material known as *pwenyet*, which is collected from the nests made by a small species of bee, is mixed with crude oil and commonly used for filling cracks and holes in timber, and for other similar purposes.

4. BRICKWORK AND MASONRY

Stone is used in forestry for many purposes, such as revetment walls, bridge abutments, paving of causeways, and in the form of metalling for roads. Stone and brick buildings are outside the scope of this book as their construction does not often fall within the duties of a Forest Ranger.

Stone is usually classified into four main groups: igneous rocks, slates, sandstones, and limestones. Igneous rocks, which are chiefly granites, are the hardest, but are not often used for forest work except for road metal as they are difficult to cut and work.

Slates are formed from clay which has been subjected to great pressures. They are close-grained and compact, and can easily be split into thin layers. Their chief use is for tiles, cisterns, and other

purposes where large flat slabs of stone are required. In forestry slates are sometimes used for revetment walling.

Sandstones are composed of fine particles of quartz cemented together by various substances such as lime or magnesia, and their durability depends on the nature of the cementing material. They can be distinguished from other stone by the fact that they will scratch steel. If the freshly broken surface of a sandstone is bright, clean, and sharp, it is probably durable, but if the surface is dull and earthy the stone is likely to weather badly. The durability of two different sandstones may also be tested by weighing them when dry, and then soaking them in water and weighing them again. The stone which absorbs the smaller percentage of water will usually be the more durable.

Limestones are composed of carbonate of lime mixed with a certain amount of silica, and vary greatly in texture and quality. Marble is a pure form of carbonate of lime, and is chiefly used in ornamental work as it will take a high polish. Limestones may be recognized by their effervescence in contact with acid.

The chief qualities to consider when selecting stone are durability and facility of working. Any stone which is durable will be sufficiently strong for any forest work for which it is likely to be required, so the actual strength of the stone need not usually be considered. In forestry, owing to the high cost of transport, the choice of stone is usually limited to whatever is available in the locality. Outcrops of good hard stone should be carefully noted when on tour, and reported to head-quarters.

Flints and very hard stones are not suitable for road metal as they will not bind. Most sandstones are too soft for roads and get quickly broken up, so limestones and igneous rocks, such as basalt and granite, are preferable for roadwork if available.

Stone is usually obtained from a quarry, although sometimes surface boulders are used. A quarry is generally sited on a hillside to facilitate working, and should if possible be at a higher elevation than the site of the work, so that the stone can be brought out downhill. If the stone in a quarry is divided by natural joints and cracks, these joints can often be used in working out the stone, by driving in wedges and then levering out the blocks with crowbars. Sometimes the stone is broken up by lighting a fire on the surface and then pouring cold water on the heated rock. A combination of drilling and wedging is also often employed in quarrying, and where these methods are not successful the rock is blasted out with explosives, as will be explained later.

Bricks. In forest work bricks are used for floors, foundations, and well steining; and for revetment walls and bridge abutments where stone is not available.

Good bricks should be of regular shape and uniform in size, with sharp, well-defined edges. They should be free from cracks, or lumps of any kind and should ring clearly when struck together or tapped with a pencil. After six hours' soaking in water, first-class bricks should not have absorbed more than about one-sixth of their dry weight. Good bricks may be of a light colour, but it will usually be found that bricks of a deep red or copper colour are best. A sound and well-burnt brick is so hard that it is not possible to make a scratch or dent on the surface with the finger-nail.

The standard size of the bricks now usually made is 9 inches by $4\frac{3}{8}$ inches by $2\frac{3}{4}$ inches, but the actual size often varies in different places and according to the method of manufacture, and bazaar bricks are often smaller than the standard. Bricks of different sizes should never be used in the same piece of work. The breadth should always be slightly less than half the length. About 1,400 bricks of standard size are required for 100 cubic feet of brickwork, allowing for the mortar-joints.

Brick earth is clay mixed with sand. If there is not enough sand the clay is 'fat' and the bricks are hard to burn and likely to crack. If there is too much sand the bricks are liable to fuse during the burning. It is not easy to tell at sight whether any particular earth will be good for brickmaking; if, however, the earth is worked up with water until it is of the softness required for moulding and is then squeezed in the hand, it is likely to make good bricks if it leaves the fingers clean. If it sticks to the fingers it is too 'fat'. A better way of testing brick earth is to mould a few bricks as an experiment and dry them in the sun. If they dry without cracking the earth will probably be good. All vegetable matter, roots, and weeds must be carefully removed from the earth before using it for brickmaking.

The best bricks are moulded on tables, and bricks which are moulded directly on the ground are usually very rough on their lower surface. The brick earth is first thoroughly ground to a fine paste, and then thrown into wooden moulds. A good moulder can make 800 to 1,000 bricks a day. A brick should be stiff enough to bear its own weight when turned out on edge from the mould. Unless the moulders are supervised they will often turn out bricks which are too soft, as this makes their work easier. After the bricks have been dried in the sun for about a month they are burnt in a kiln. With a well-designed kiln 100 cubic feet of wood fuel should be sufficient for 1,000 bricks.

Mortar. This consists of lime or cement mixed with other materials to form a paste, which is used in masonry to bind together the bricks or stones, and also to give them an even bed by filling up their inequalities. Mortar is also used as plaster to provide a smooth hard surface to a wall or other structure. The lime used for mortar is 'slaked' lime, which is produced by adding water to 'quick-lime'. Quicklime, or calcium oxide, is obtained by burning natural limestone. Pure slaked lime alone is not used for mortar, as it does not harden or 'set' except at the surface; it is therefore always mixed with sand, or with burnt and broken bricks ground to a fine powder which is called *surkhi* in India and *ok hmone* in Burma. The proportion of lime used depends upon the class of work, but a mixture of equal parts of lime, sand, and *surkhi* is commonly used.

The mortar must be well ground, and stirred continuously while grinding, so that all parts are thoroughly mixed. It must be used as soon as possible after grinding, and contractors should not be allowed to use lime mortar which has been made more than twelve hours previously.

Certain limes which are found in a natural state mixed with clay, magnesia, and iron, will 'set' or harden under water; and a lime mixture is called 'hydraulic' if it has begun to set hard within seven days under water. If available, hydraulic lime mortar should be used for all permanent work, especially for brick steining in wells and for bridge abutments, unless cement mortar is obtainable.

Mortar made either with hydraulic lime or with cement is weakened if allowed to dry too quickly. It is therefore important, especially during hot weather, that the bricks or stones to be embedded in the mortar should first be well soaked in water so that they will not absorb the moisture from the mortar. The work should also be kept thoroughly wetted for a week or ten days after it has been laid.

Mortar should be used as stiff as it can be spread. Thin liquid mortar, called 'grout', is sometimes poured over courses of masonry so that it will penetrate into empty joints caused by bad workmanship. Grout has very little strength, and should not be allowed except in deep and narrow joints such as in rubble walling, which sometimes cannot be filled up with proper mortar.

Mortar should never be more than $\frac{3}{8}$ inch thick between bricks, and from 25 to 30 cubic feet of mortar is required for 100 cubic feet of brickwork walling. A mason should lay about 300 bricks a day, which is nearly 25 cubic feet of walling.

Cement. Cement is used instead of hydraulic lime in mortar for important structures, especially for dams, reservoirs, water channels,

and foundations under water. It is often used for 'pointing' or facing over ordinary lime mortar in brickwork, and also as cement plaster. It sets very hard, and is much stronger and more durable than even the best hydraulic lime. It must be used within half an hour after mixing. For works of importance, where special strength is required, cement mortar is sometimes made with one part of cement to two parts of sand, but for ordinary purposes one part of cement to four or five parts of sand is sufficient.

Many different brands and qualities of cement are sold, and the refilling of old barrels with inferior cements or mixtures of lime and cement is very common, so care is necessary when purchasing cement from the bazaar to see that a well-known brand is supplied in the original barrels intact. Good cement is now manufactured in India, but the best quality comes from England and is known as Portland cement.

Concrete. Concrete, which is a form of artificial stone, is made by mixing lime or cement with sand or *surkhi* and adding some hard material such as broken stone, or gravel. The broken material is called the 'aggregate', and the mortar in which it is embedded is called the 'matrix'. For forest work the aggregate is generally any hard material that can be procured near at hand without great expense, such as broken brick, sandstone, limestone or laterite, and sometimes gravel or shingle. The material is usually broken up to an average size that will pass through a $1\frac{1}{2}$ inch or 2 inch mesh, but for important work it should be much smaller, down to $\frac{3}{4}$ inch.

The aggregate and mortar must be thoroughly mixed together. Four-sided frames or 'boxes', about 5 feet square, are used both for measuring and mixing the concrete. In the case of cement concrete, which is mixed dry, the best method is first to box the aggregate and then to box the sand on top of the aggregate. The cement is then spread over the sand. Working from the bottom of this mound, which is composed of the three unmixed ingredients, the whole material is then mixed by shovelling it to a new position at least the width of the mound away from its original position. Water is then added to form a loose mixture, which is carefully laid where required, in horizontal layers not more than 6 inches thick, and each layer is rammed hard to make it compact. Concrete should never be thrown into position from a height, as gravity then causes the various ingredients to separate. The proportions of cement to aggregate in cement concrete vary according to the work for which it is used, but for bridge work, one part cement, two of sand, and four of broken stone or shingle, is the usual mixture.

Lime concrete is mixed when wet, in the same way as lime mortar. The usual proportions of matrix to aggregate for lime concrete is one part of lime mortar to three parts of aggregate. For walls, culverts, and bridges the proportion is increased to one part of lime mortar to two parts of aggregate. In Burma the cost of concrete of broken stone in lime mortar is about 40 rupees per 100 cubic feet; and in cement mortar the cost is almost three times as much.

Where large masses of concrete are used, as in heavy foundations or bridge abutments, it is usual to pack into the interior large lumps of stone or brick called 'plums', for the sake of economy. These 'plums' should be placed at least 3 inches apart, and not near the surface, so that they are entirely surrounded by cementing material.

Plaster. For lining the inside of water-channels and wells, and also for floors of buildings, cement plaster is generally used. The plaster, which is usually made of two parts of sand to one part of Portland cement, is laid to a depth of about half an inch.

Lime plaster is used for less important work. Lime which is only very slightly hydraulic should be used, and a common mixture is two parts lime paste, one part *surkhi*, and three parts clean sharp sand. To this is added a small quantity of chopped hemp or some ox hair.

When brickwork is being plastered it should be thoroughly wetted before the plastering is applied, and all mortar joints should be raked out to a depth of $\frac{3}{4}$ inch. One coat of plaster is usually sufficient for ordinary brick walling, and it should not exceed $\frac{1}{2}$ inch in thickness. The surface is finished off with a wash of pure lime paste. The plaster is kept well sprinkled for 4 or 5 days, with water containing gum or sugar, and must be well beaten with hand tappers.

5. MISCELLANEOUS MATERIALS

Bamboo. In Burma, Siam, and other tropical countries where bamboo is plentiful, it is often the chief material used in forest buildings. For temporary buildings the whole structure may be of bamboo, but for more important buildings it is customary to use timber for the posts and main supports, and bamboo for the walls and roofs.

Bamboos should never be cut until they are fully mature, which is usually not until their third year. Green bamboos tend to crack and are not durable. As soon as possible after cutting, all bamboos should be soaked in fresh water for at least ten days, preferably in a running stream, and then stacked in the shade with a free circulation of air until dry. The soaking in water renders them less liable to attack by the common bamboo shot borer.

II. (*a*) Splitting and weaving bamboo mat-walling for forest buildings.
(*b*) Weaving bamboo strips into six-foot sections ready for roofing.

Bamboos used for furniture-making are often soaked previously in crude earth-oil, and bamboo-posts and mat-walling should be oiled every year as a protection against insects and decay. *Bambusa polymorpha*, *Dendrocalamus strictus*, and *Cephalostachyum pergracile* are the species of bamboo most commonly used in Burma for general constructional purposes, the last two being also used for bamboo-matting.

Thatch. The thatch used for forest buildings is usually made from any long coarse grass which is locally available. *Imperata arundinacea*, or *thekké* grass, is abundant in most parts of Burma and Siam, and roofs thatched with it are very common in most localities where the rainfall is not too heavy. The grass should be cut at the time of flowering, about the end of February. There is a tendency to cut the grass too early in the season in order to realize earlier and bigger prices, but if it is cut too soon the blades are less durable. This may be partly owing to the heavy dew at night rotting the grass while it is lying in the open, but is more probably due to the grass not being thoroughly mature. Good quality thatch should last three years if properly laid, with the strips not more than 2 inches apart. The method of use of the grass, and the construction of a thatched roof, will be dealt with later under building construction.

Palm-leaves. Palm-leaves of various kinds are commonly used in tropical countries for the roofing of forest buildings. The leaves of *Nipa fruticans*, or the *dani* palm, are used in many parts of Burma. The branches of this palm resemble those of the coco-nut palm. The leaves are stripped off the branch, folded double over a bamboo stick, and then stitched to each other by thin strips of wood or bamboo. If mature leaves are used, *dani* roofing will last three years, except in very exposed localities where damage by wind is great.

Licuala peltata or *salu* is another palm which is very commonly used as a roof covering in Burma. It is not so strong or durable as *Nipa fruticans*, and usually requires renewal annually, although in some cases it may last for two years. It is one of the cheapest forms of roof covering, and it is very useful for temporary huts or coolie shelters in the forests.

II

CARPENTRY JOINTS AND FASTENINGS

1. MAIN PRINCIPLES OF CARPENTRY

HAVING made, in the last chapter, a brief study of some of the commoner engineering materials, we can now consider the use of these materials in actual practice; but before dealing with the construction of any particular forest building in detail we shall first consider a few of the general principles on which the design and construction of timber buildings are based.

The art of shaping and combining pieces of timber to support weight or to form woodwork structures is called carpentry. The nature of timber is such that great care is necessary in the design and formation of all joints and fastenings to ensure that the strength of the timber is maintained and is sufficient to withstand the action of any loads or forces which it is required to meet. Hence the study of carpentry involves a knowledge of the forces, or stresses, to which all timber used in construction is subjected. These stresses may be roughly divided into four kinds:

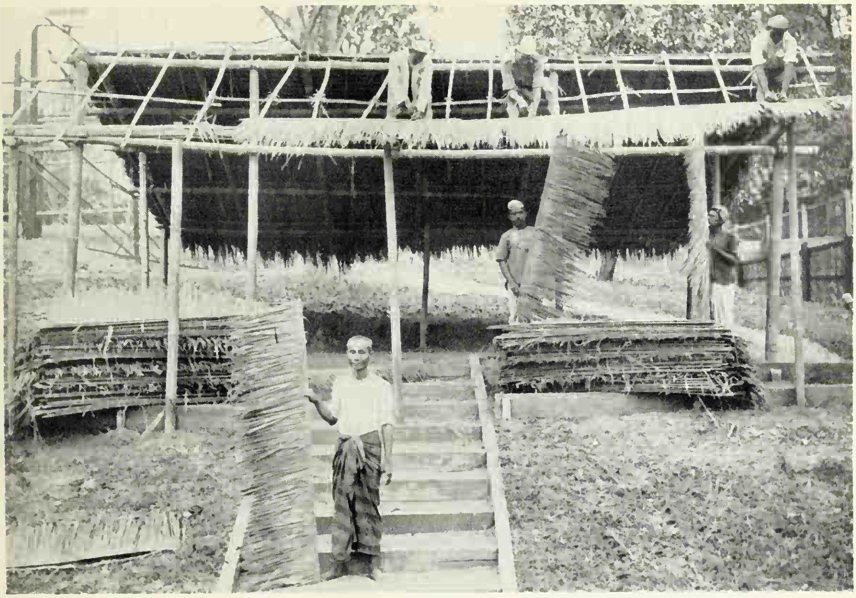
(1) Timbers are said to be in 'tension' when subjected to a length-stretching or pulling force, as in the case of a tie-beam, and all parts of a structure wholly in tension may be considered as 'ties'. Tension tends to cause the fibres of the wood to tear apart.

(2) Timber subjected to a crushing or pushing force is said to be under 'compression' as in a short pillar, and all parts under compression may be considered as 'struts'.

(3) If a load or pressure is applied at right angles to the length of a beam supported only at its ends, it will cause a 'transverse' or cross-strain, as when a floor-joist or girder-bridge is carrying weight. The timber under a transverse strain first tends to bend and then to break across.

(4) A cutting or sliding stress, as when a piece of paper is cut by a pair of scissors is called 'shearing'. It is not often of much importance in timber-work except in the case of bolts and other fastenings 'shearing' through timber when they are placed too near the ends.

The method of calculating the strength of beams is dealt with in Chapter VIII, under Bridging, and here we have only to consider the



III. (*a*) Thatching a temporary bamboo roof with grass.

(*b*) Thatched roof of typical foresters' quarters, in Upper Burma.

effects of forces on timber joints. The following principles should always be observed when designing timber joints and fastenings:

(*a*) Joints should be cut and fastenings arranged so that the timbers which are connected are weakened as little as possible, and the fastenings should also be so proportioned that they are of equal strength to the pieces which they connect.

(*b*) Each abutting surface in a joint should be made as nearly as possible at right angles to the pressure which it has to transmit, and the parts which take the strain should be given the greatest possible amount of effective surface.

(*c*) Each pair of surfaces should be fitted carefully and accurately in order to distribute the stress evenly. If this is not done the timber tends to split owing to the unequal pressure or tension in the fibres. To ensure an equal bearing a sawcut is often made between a pair of abutting surfaces after the pieces are put together.

(*d*) The joints should be arranged so that they are affected as little as possible by expansion or contraction of the wood. This is very important in the case of forest buildings and bridges, where timber is often used before it is seasoned or dry.

(*e*) The simplest form of joint should always be selected, in order to obtain the smallest possible number of abutting surfaces, as the more complicated the joint the less probability there will be of getting a sound, firm, and even connexion. This is particularly necessary in places where highly-skilled carpenters are not available.

2. JOINTS USED FOR LENGTHENING TIMBERS

For many requirements, such as beams and rafters in roofing, and girders in bridging, timber of sufficient length cannot be obtained, and it then becomes necessary to unite two or more pieces lengthwise. This may be done by lap-joints, butted and fished joints, or scarf-joints.

Lap-joint (see fig. 1). This is the simplest means of uniting two pieces of timber. The end of one is made to overlap that of the other, and the whole is secured by nails, straps, or bolts. Bolts are cheaper, and neater in appearance than straps, but the bolt-holes weaken the timber. Timbers joined by lapping will not be in the same plane, but where two joints are made in the same timber the end pieces are brought into line again. Lap-joints should be used in rough work and temporary buildings only, as the joints are clumsy in appearance, but they are strong and are also easily made.

Butted and fished joint (see fig. 2). This is the best joint for

general purposes. The ends of the timbers are simply butted together and united by plates of wood or iron, known as 'fish-plates', bolted on opposite sides of the timber. The length of the fish-plates should be at least four times the thickness of the timber to be joined, and if wooden plates are used the thickness of each plate should be about half the thickness of the timber joined; if iron plates are used, as shown in the drawing, the usual thickness is $\frac{1}{4}$ inch or $\frac{3}{8}$ inch.

A reference to fig. 2 will show that the bolts are placed zigzag instead of in a straight line. This distributes the strain, and also lessens the tendency of the wood to split down the centre. For the same reason straps are sometimes used instead of bolts, but a great disadvantage in using straps is that they become loose if the timber shrinks.

Butted and fished joints are easy to make, and are often used in forest structures for lengthening timbers under compression. For joints under strong compression, especially in vertical posts or struts, fish-plates are often applied to all four sides; and for joints under transverse strain one fish-plate alone may be used on the lower side.

Scarfing or splicing. Scarfing should be used for joining timber in the direction of its length if neatness is necessary as well as strength. It is done by cutting away corresponding portions of the thickness at the ends of the pieces to be joined. The remaining parts are overlapped and secured by bolts, straps, or fish-plates, according to the nature of the strains to which the joints will be subjected.

In fig. 3, one-half of the thickness has been removed from each piece. This is termed a half-lap or halved joint. In fig. 4 the surfaces are cut to a bevel. If the joint is kept perfectly tight by means of bolts or straps the wedge-shaped portions tend to prevent the separation of the timber when subjected to tension.

Many elaborate types of scarf-joints were formerly used, with 'indentations' or 'tables' designed to hold them in position and to take the stresses, but these are now generally replaced by simpler joints assisted by iron plates and bolts, as shown above, and the latter are much more suitable for forest work. A halved or scarfed joint is nearly always strengthened by the addition of fish-plates, which should be prolonged at each end beyond the joint so that the bolts can be inserted through the whole depth of the uncut part of the timber. Scarf-joints should be made over a point of support where possible, so that all transverse strain on the joint is avoided.

Scarf-joint for transverse strain. In the case of a transverse strain, such as the load on a bridge girder, the lower half of the girder is under tension and the upper half is under compression. This can

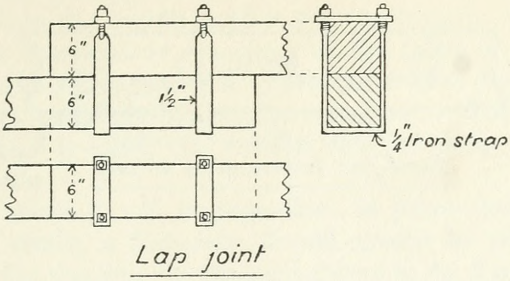


FIG. 1

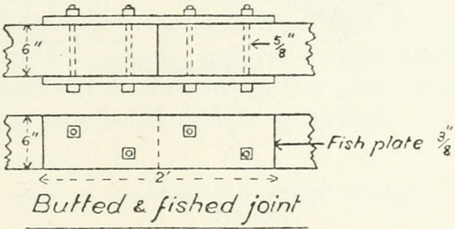


FIG. 2

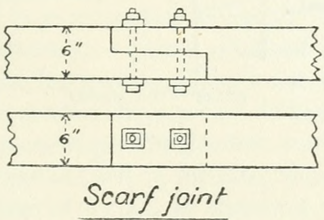


FIG. 3

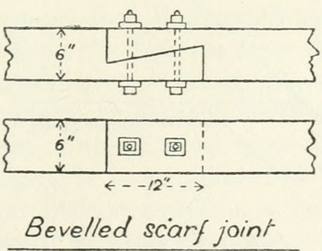
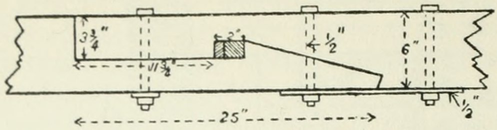
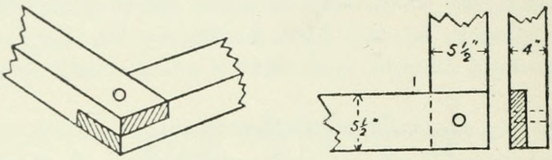


FIG. 4



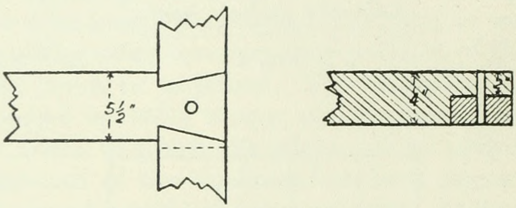
Joint for transverse strain

Fig. 5



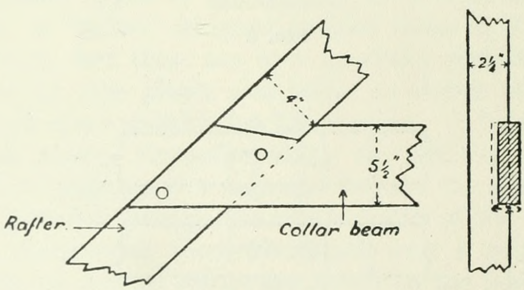
Halved joint

Fig. 6



Dove-tail joint

Fig. 7



Halved joint in roof truss

Fig. 8

easily be tested by supporting a small beam at both ends and gradually loading it in the middle until it breaks through. If the fibres of the wood are then closely examined at the point of rupture it will be seen that the fibres near the upper edge have been compressed and the fibres near the lower edge torn apart. The middle line of the beam, which is called the 'neutral axis', is under neither tension nor compression.

From the above it will be seen that, in joints designed to resist a transverse strain, a fish-plate should always be placed *below* the joint to take the tension. In the joint shown in fig. 5 a short fish-plate is shown covering the joint on the lower side, while the upper half of the joint is cut square to resist compression. The two pieces are forced up into close contact by driving in the two keys, shown at the centre, which are slightly wedge-shaped. This is a good form of joint where neatness is required, but for bridge timbers and forest buildings a simple butt-joint, with strong fish-plates above and below, as shown in fig. 2, is usually all that is necessary.

3. JOINTS IN TIMBER STRUCTURES

Halving. In the case of wall-plates or beams which are resting on other timbers, halving is the most common joint used. Fig. 6 shows two pieces joined together in this way at right angles.

Dovetail halving is represented in fig. 7. This shows in plan and section the joint between two pieces of wood at right angles to each other. The end of the horizontal piece is cut down to one-half of its original thickness, the portion thus reduced then being cut to a dovetail form. This fits into a corresponding notch worked in the lower piece. A joint of a similar kind is used in forming the connexion between the collar-beam and rafters of a roof, as shown in fig. 8. The end of the collar-beam in the example is cut to a half dovetail form, and checked out to a depth of $\frac{1}{2}$ inch. The rafter is notched $\frac{1}{2}$ inch deep to receive the collar-beam. Nails or pins then secure the whole. Dovetail joints should only be used in well-seasoned timbers, as even a small degree of shrinkage allows the joint to draw slightly out of its place.

Notching. A common way of fitting floor-joists to post-plates is shown in fig. 9. The joists are slightly checked out or 'notched', and then are usually spiked or nailed to the post-plate. If it is necessary that the notch be deep, it is advisable, in order to diminish the strength of the joist as little as possible, to cut half of it out of each timber. This is generally known as double notching.

Mortise and tenon. This is a joint very frequently used in

carpentry, especially where a vertical piece of timber is to be joined to a horizontal one. The tenon is formed by dividing the end of the timber into three equal parts and cutting out the rectangular pieces at the sides, leaving the third portion in the middle, as shown in fig. 10. A rectangular hole or 'mortise' cut in the other piece receives the tenon. When the tenon does not pass right through the lower piece the mortise should be cut a little deeper than the length of the tenon in order that the 'shoulders' of the tenon and not its end will receive the weight, as shown in the figure.

Housed tenon. A horizontal section through a post and rail is given in fig. 11. In addition to the mortise and tenon the whole end of the rail is let into the post for a distance of one inch. By this means the strength of the joint is greatly increased, as any weight to which the rail may be subjected is carried by the whole thickness of the timber instead of by the tenon only.

Oblique tenons are used when the timbers are not at right angles. Fig. 12 shows a roof-rafter and tie-beam joined by an oblique tenon. The tenon is indicated by the dotted line. Care should be taken to keep the mortise as shallow as possible in order not to weaken the tie-beam. The rafter is usually also secured by means of bolts or straps, the position of which is indicated by the chain dotted line.

Figs. 13 and 14 show the method of joining an inclined strut to a post, the timbers chosen for illustration being the principal rafter and the king-post of a wooden roof-truss.

In fig. 13 the head of the king-post is large enough to allow of a square abutment the whole depth of the rafter. This is not the case in fig. 14. The end of the rafter has therefore been cut so that a portion at least of the bearing surface is at right angles to the direction of the pressure. The upper part of the joint should be left slightly open, so that when the framing settles into its position the pressure will be evenly distributed.

Fig. 15 represents two forms of the joint between a strut and the foot of a king-post. The present practice is to use short stub tenons, as shown on the left of the figure, as these are sufficient to prevent the pieces from moving laterally, which is all that is required of the tenons in joints under straight compression.

Bridle-joint. Fig. 16 shows the form of connexion used at the foot of a principal rafter. The central tenon or 'bridle' is formed on the tie-beam and the corresponding mortise is cut in the rafter. This form of joint presents a large bearing surface. The heel-strap shown in the illustration is arranged so as to take the thrust of the rafter and thus assist the joint.

Notching

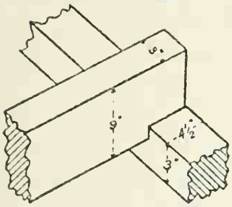


FIG. 9

Mortise & tenon

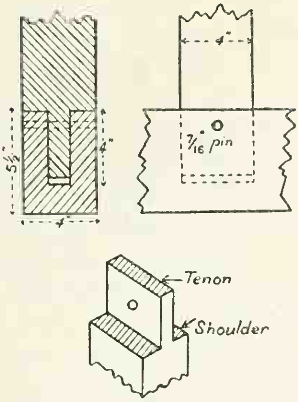


FIG. 10

Housed tenon

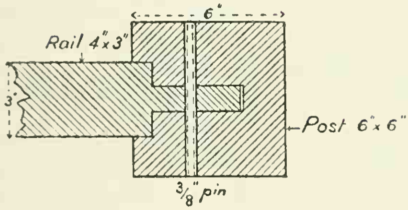


FIG. 11

Oblique joint with square abutment

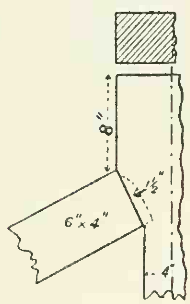


FIG. 13

Oblique tenon

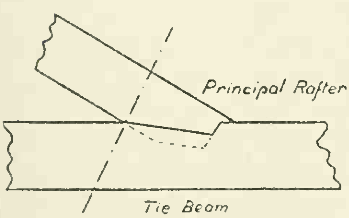


FIG. 12

Joint at head of King Post

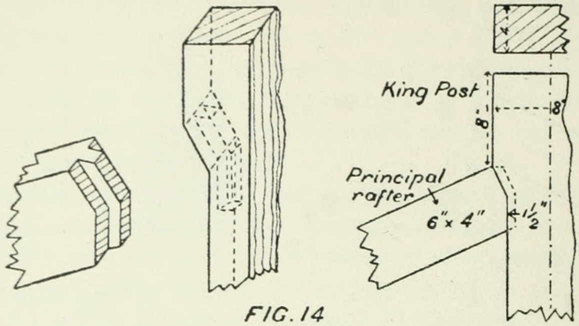


FIG. 14

Bearing joints at base of struts

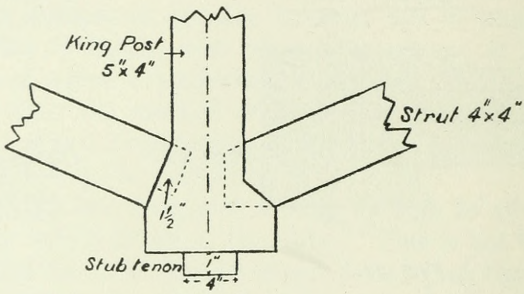


FIG. 15

Bridle joint with heel strap

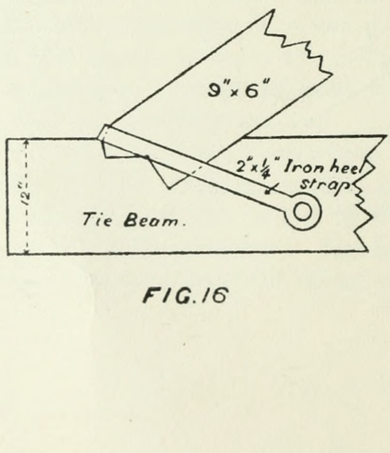


FIG. 16

4. JOINTS IN PLANKING AND BOARDING

The following joints are used in the construction of plank doors, partitions, floors, and boarding generally:

Butt-joint. This is formed by simply planing the edges of the boards true, and placing them in contact. Fig. 17 shows, in section, two floor-boards butt-joined and nailed to the joist. The chief defect is that when shrinkage occurs in width an opening will be left through the whole depth of the boards which allows dust to pass through, and this type of joint is only suitable for rough temporary buildings.

Rebated joint. In this form of joint a rectangular strip is cut from the edge of each board and the remaining portions are overlapped, as in fig. 18. The drawback mentioned in the last case is here avoided. This joint is more often used in board partitions than for flooring.

Rebated and filleted joint (see fig. 19). This is used chiefly in flooring. A rebate is worked along the lower edge of each board, into which is placed a strip of hard wood termed a 'fillet'. The rebate is often made of less depth than is shown in the drawing to allow of heavy wear on the flooring before the fillet is exposed.

Tongued and grooved joint (see fig. 20). Along the edge of one board a tongue is made by a special cutting-machine. The tongue fits into a groove cut in the edge of the adjoining board. This form of joint allows of hidden nailing. The nails are driven in on one edge only, as shown in the drawing.

Where the above forms of joints are used for flooring, the rebates, tongues, and grooves should be kept as close to the lower face of the floor boards as possible, as all wear comes on the top of the boards. The object, therefore, is to meet this wear by leaving a greater thickness of the material where it is most required. In laying a floor of tongued and grooved planking, it should be seen that the thicker edge is always placed on the top.

5. IRONWORK FASTENINGS

The fastenings described below are commonly used in constructional work. Where possible, the use of iron fastenings should be avoided in forestry work as they are expensive, and when used on bridges and exposed buildings in the forests they are frequently stolen and cause considerable trouble. Badly forged and inferior iron should never be used for bridges or other important structures owing to the uncertainty of its strength.

Bolts and nuts. Bolts are used to fasten timber together and to give additional security to timber joints, many forms of which depend

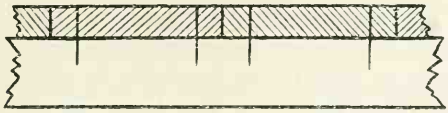
upon them altogether for strength. As already mentioned, the use of bolts has the disadvantage of weakening the beams through which they pass by cutting the fibres. If the timber shrinks they become loose and bruise the grain of the wood where they bear on it. Iron washers should always be placed under the bolt-heads as well as under the nuts, to increase the bearing surface. The depth of a nut is usually equal to the diameter of the bolt, and the thickness of a washer one-third of the diameter. When estimating the length of bolt required an allowance for a nut and two washers must always be made. Where bolts or nuts are likely to be stolen, as when exposed on forest bridges, the screw-threads on the protruding part of the bolts should be hammered over and destroyed, after the nut is in position, as this will prevent removal of the nuts. It should be noted that bolts are intended to hold timbers firmly together, and not to take the strain themselves, and where possible they should be retightened after the timber has shrunk.

Straps. Straps are bands of wrought iron about $1\frac{1}{2}$ to 2 inches in breadth, and with a thickness depending upon the quality of the iron and the stress upon it. They are often used instead of bolts to strengthen or to form joints. They do not cut through and weaken the timber, but are apt to get loose when the timber shrinks, so should not be used on unseasoned timber. They should be placed and fitted so that the stress will come upon them in the direction of their length as nearly as possible.

Plates. Straight iron plates are used with bolts or screws to form fished joints or to strengthen timber under tension. For heavy bridge work they are often $\frac{1}{2}$ inch thick.

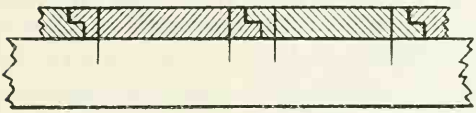
Bent iron plates are usually made out of $\frac{1}{4}$-inch iron, and can be easily cut and bent into any shape required. They are used chiefly to strengthen joints or to prevent lateral movement.

Nails and spikes. Nails and their uses are too well known to need much description. It is worth noting, however, that there are two distinct kinds of nails, 'cut' clasps which are sheared or stamped by machinery out of iron or steel plates, and 'wrought' nails which are made of wrought iron. The cut nails are cheaper, but most kinds are rather brittle. They are blunt-pointed, and have two parallel sides which should be placed in the direction of the grain of the wood, to reduce the tendency of the nail to split the wood. Wrought nails do not easily break, and can be bent or clenched over where it is desired to draw and hold two pieces of wood together. When nails are used to fasten boards to joints or beams, their length should be $2\frac{1}{2}$ times the thickness of the board. Wire nails, which



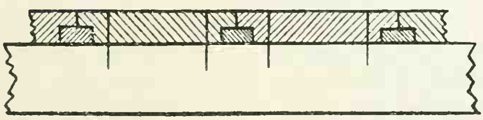
Butted joint

Fig. 17



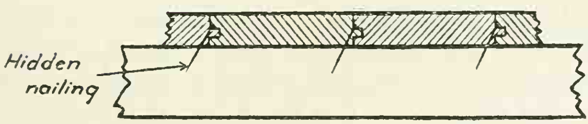
Rebated joint

Fig. 18



Rebated joint with fillets

Fig. 19



Tongued & grooved joint

Fig. 20

are circular in section, are very tough and strong and are used in box-making.

Spikes are of the same shape as cut nails, but are from 4 to 10 inches long, and are used for heavy timber-work. When driven through timbers which acts as ties the spikes should not be less than nine inches from the ends of the ties. The heads of spikes should not be driven in flush with the surface of the wood, as this tends to break them off, and as in the case of nails the spikes should be driven so that the widest edge is across the grain, as this is less likely to split the wood. When using spikes for joining two pieces of timber, auger holes slightly smaller than the size of the spikes, should be bored through the first piece of timber, but the spikes will force their own way into the second piece, generally with the grain. Spikes are purchased by weight, usually in hundredweight barrels. There are about 1,000 five-inch spikes to the hundredweight, and about 330 seven-inch spikes.

Screws. Screws are used in situations where the work may afterwards require to be taken to pieces, and also in cases where driving a nail might split the timber. They are also used for attaching iron straps or hinges to timber and are more secure than nails. Some non-acid grease should always be put on iron screws when driving them, and where screws are used in damp places they should be of copper or brass, otherwise they will rust and be difficult to withdraw. For heavy timber-work screws with square heads, called 'coach screws', are generally used.

Dogs, or dog-irons, are short pieces of wrought iron with both ends pointed and bent over at right angles to form teeth. The dogs may be from 9 to 18 inches long, the teeth from 3 to 8 inches long. Dogs are made from bar iron, of section from $\frac{1}{2}$ to $\frac{3}{4}$ inch, a square section being best.

They are used for fastening the frames of heavy timber, particularly in temporary bridge-work. The position of each must be chosen with the definite object of preventing a possible distortion or movement of the frame, and they must be used on both sides of the frame. The teeth should not be driven within 3 inches of the edge or 4 inches of the end of a piece of timber. For large dogs it is usual to bore an auger hole for the teeth of the dog, slightly smaller than the section of the iron. They can be withdrawn by inserting a crowbar under the shank.

Drift-bolts are pieces of round or square iron, without heads or points, driven like spikes, but always into holes previously bored in the timber. They are usually more satisfactory than dogs for permanent work, and are used very extensively in heavy bridge and

pile work. A drift-bolt acts like a nail, not only preventing lateral, or side, movement, but also separation of the timber in the direction of the axis of the bolt. The diameter of the hole to be bored to receive a drift-bolt should be about four-fifths of the diameter of the bolt. Thus for a $1\frac{1}{4}$-inch bolt the hole should be one inch. This proportion develops the maximum holding power.

Heads are objectionable, as they crush the fibres on being driven into the wood, and form cavities in which rain-water lodges and causes decay. If the hole is smaller than the bolt a sufficient head for all purposes will be formed by the burring or spreading of the metal when driven. The hole should be drilled completely through the upper timber and into the lower timber for a depth of about three-quarters of the distance to which the bolt will finally penetrate. The bolt should be long enough to give a good hold into the last timber into which it is driven, and for joining 12-inch timbers drift-bolts should be at least 20 inches long. In bridge construction drift-bolts are generally about $\frac{3}{4}$ inch in diameter.

The holding power of drift-bolts driven perpendicularly to the fibres is approximately double that when driven parallel to the fibres, for both hard and soft woods.

6. WOODEN FASTENINGS

Trenails. Trenails are large wooden pegs or pins, made of straight grained hardwood, such as teak, and are used in a similar manner to nails and spikes. They are useful in places where iron nails might rust, especially in shipbuilding, and are also used for appearance in carpentry and joinery work. Compressed trenails are often used on railways, as they expand on exposure to moisture and make very firm joints. They are also used in timber framing to secure and draw together mortise and tenon joints.

Trenails should always be cleft from the log, to avoid cutting into the longitudinal fibres. They are sometimes made by splitting them roughly and then hammering them through a nut or die-plate to shape them, but there are also special machines for splitting trenails. The best section is square or polygonal. An auger hole must be made for trenails, and it is customary to drive a square trenail into a circular hole, the diameter of the circle being equal to, or a little larger than, the side of the square. By putting one sledge-hammer against the trenail head and striking this hammer with a second one, a trenail can be driven without being split. If a longitudinal sawcut be made in the outer end of the trenail, when the latter is in place a thin wedge can be driven into the cut to tighten it.

Good durable trenails can be split from the culm of large bamboos, such as *Dendrocalamus strictus*.

Dowel-pins. When it is required to keep two pieces of timber in position but yet allow for any shrinkage of the wood, a hole is bored in each piece of timber to a certain depth and a cylindrical wooden peg or dowel-pin is inserted so that half the pin is in each hole. When these dowel-pins are made of hardwood they are similar to trenails, and are only distinguished from them by their special use. Dowel-pins made of iron are commonly used in machine construction.

III

FOREST BUILDINGS

1. SELECTION AND CLEARING OF SITE

FOREST buildings consist chiefly of rest-houses for the use of officers on tour, and of more permanent quarters for Forest Rangers and other Subordinates. In addition there are the usual accessory buildings such as servants' quarters, stables, and cook-houses.

The chief considerations which govern the choice of a site for a forest building are the water-supply, the nature of the soil, the elevation, the facilities for drainage, and the general situation and accessibility.

(1) A good water-supply is essential, either from a well or from a running stream. This is of great importance, and we shall deal more fully with wells and water-supply in a separate chapter. If the building is to be erected on the banks of a stream near a village the site should be selected upstream from the village. Care should be taken that the site is not too near the stream if the banks are at all liable to erosion, or if the stream is likely to change its course.

(2) Gravel or sand is the best form of soil, as it ensures good drainage. Clay soils are impermeable and hold moisture even when drained.

(3) A site slightly raised above the surroundings, and with a good view, should be chosen for rest-houses and permanent quarters where possible. The building should face as nearly as possible north-east in order to avoid the hot afternoon sun, and also to get the advantage of the prevailing winds. This aspect also secures protection from the south-west monsoon rains.

(4) A building must of course be conveniently situated with regard to the particular purpose for which it is required. A Forest Subordinate's quarters should be as near as possible to the centre of his working charge, but must also be easily accessible and near to a village where supplies can be obtained. Permanent quarters for Subordinates are nearly always built in or close to a village for social reasons. Forest rest-houses should be far enough from a village and main road to escape the noise and dust from passing traffic, but should be easily accessible. They should only be erected where the amount of work in the vicinity would justify the expenditure, or where they are required for halting places on the main routes of communication.

Sites for forest buildings should be completely cleared of all tree-stumps and rubbish, and any nests of white ants found in the vicinity should be destroyed. Trees on the actual site should not be felled, but should be uprooted by digging, as this ensures the complete extraction of the stumps and roots. If the site is well chosen no special drainage system should usually be necessary except a few shallow trenches round the buildings to collect and carry away rain-water. Any surface water from higher adjoining land should be intercepted and diverted by a cross-drain, which should follow the boundary fence if possible. Undergrowth or dense masses of trees should be cleared for a considerable distance round the site, as in addition to the danger from fire to the building and dampness during the rains, dense vegetation harbours mosquitoes and is unhealthy.

2. TYPE PLANS FOR FOREST BUILDINGS

Forest rest-houses and Subordinates' quarters are usually built according to standard plans issued by the Forest Department. These plans include designs for Rangers' and Foresters' quarters, and for several different grades or classes of forest rest-houses.

The standard design for a first-class forest rest-house in Burma is shown on a reduced scale in fig. 21, page 33. It will be seen that the building is intended to accommodate two officers and that the two bedrooms are of equal size. This necessitates a double row of posts in the middle of the building to admit of a central passage between the two rooms, and also entails certain difficulties in the roofing, as will be explained later. Most forest rest-houses are now being built in this form in Burma, but it is questionable if the convenience of having both bedrooms of equal size justifies the extra cost entailed. With reference to fig. 21 it should be noted that the five house-posts under the central part of the verandah are cut off at floor level, and the two hip-rafters are supported in the middle by vertical struts (*S*) which rest on tie-beams, spiked or bolted to the adjoining house-posts at the height of the post-plates. This leaves the verandah clear of posts. The post (*P*) shown in the sectional elevation in fig. 21 is, of course, the post on the far side of the verandah which is shown in cross-section in the plan. The open extension shown in front is often omitted for economy, but adds greatly to the amenities of the building. A photograph of a typical forest rest-house under construction is shown on plate IV.

Standard plans for a cook-house and for a latrine are shown in fig. 22, page 34. The designs for these accessory buildings are the

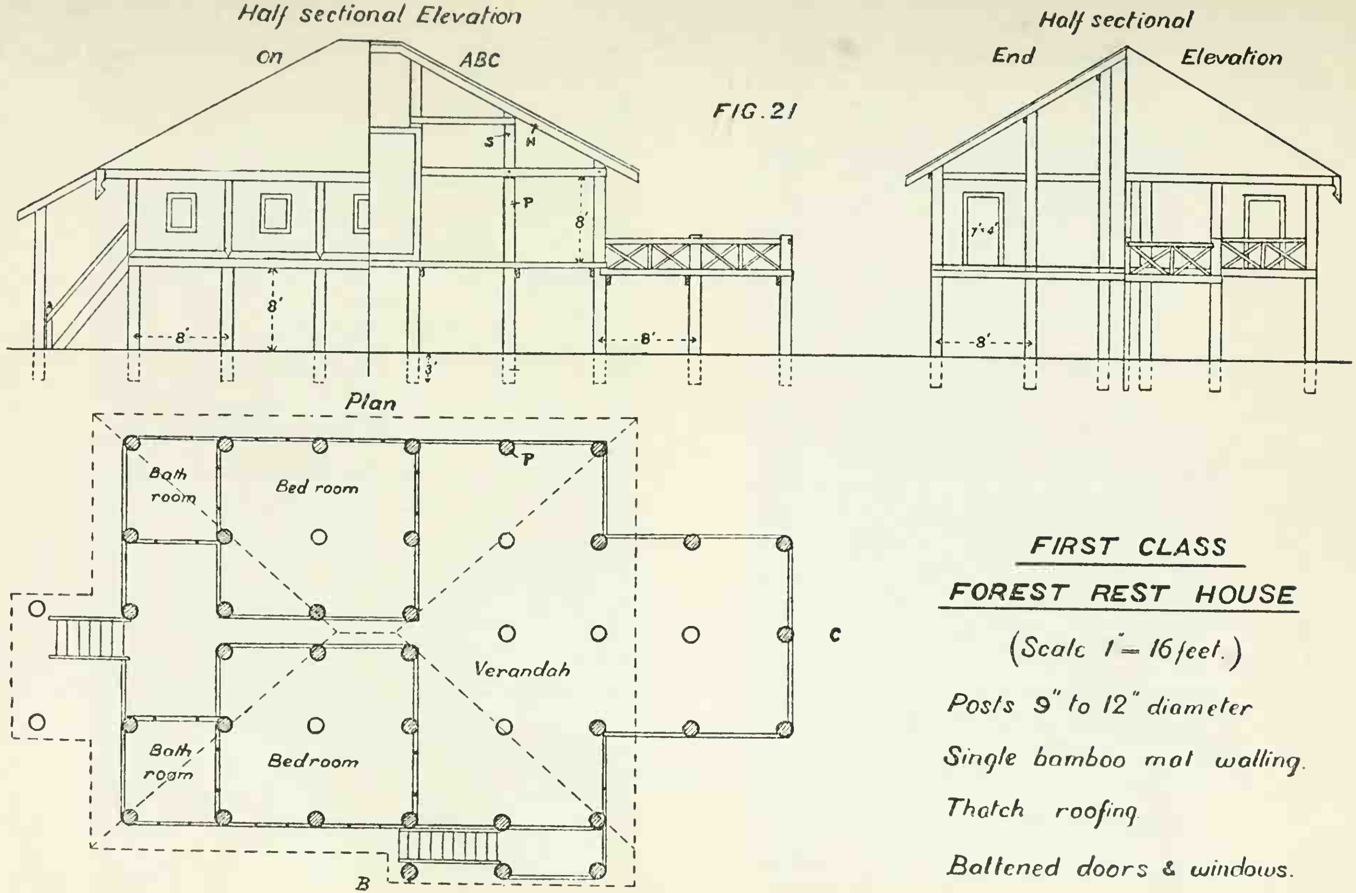


FIG. 21

FIRST CLASS
FOREST REST HOUSE

(Scale 1" = 16 feet.)

Posts 9" to 12" diameter

Single bamboo mat walling.

Thatch roofing.

Battened doors & windows.

3554

F

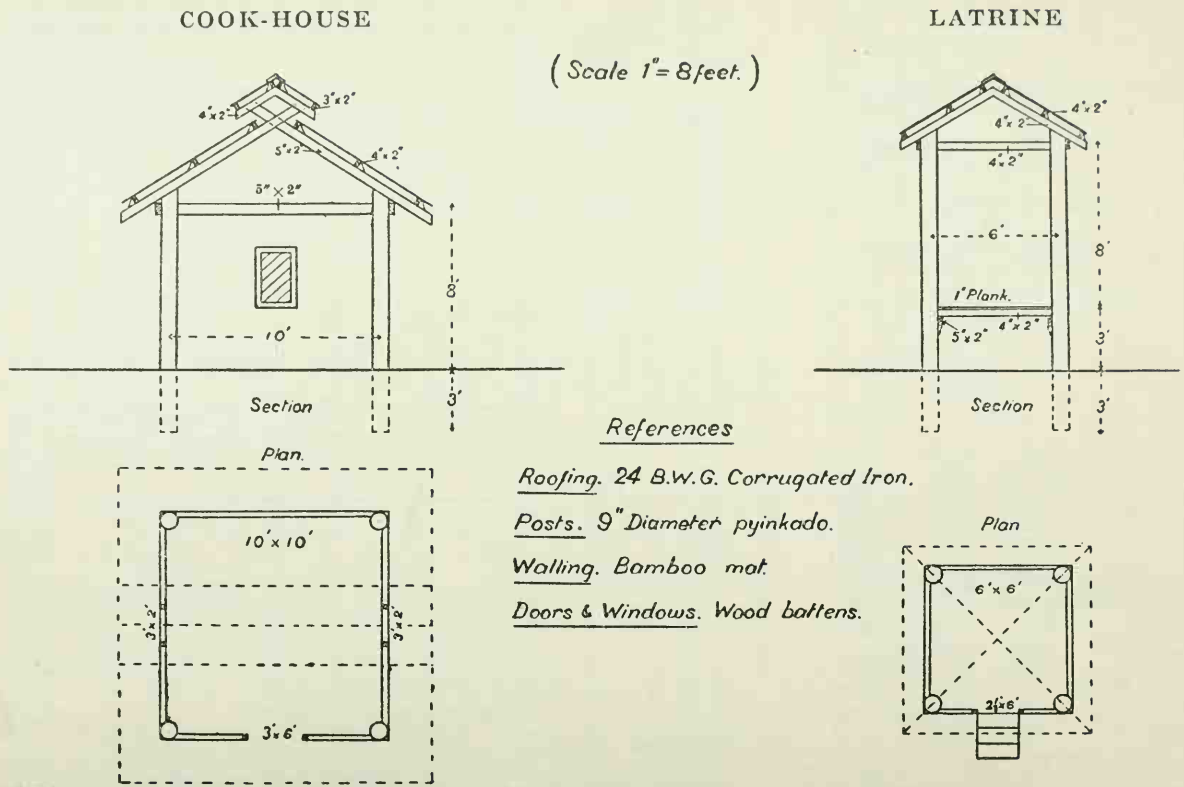
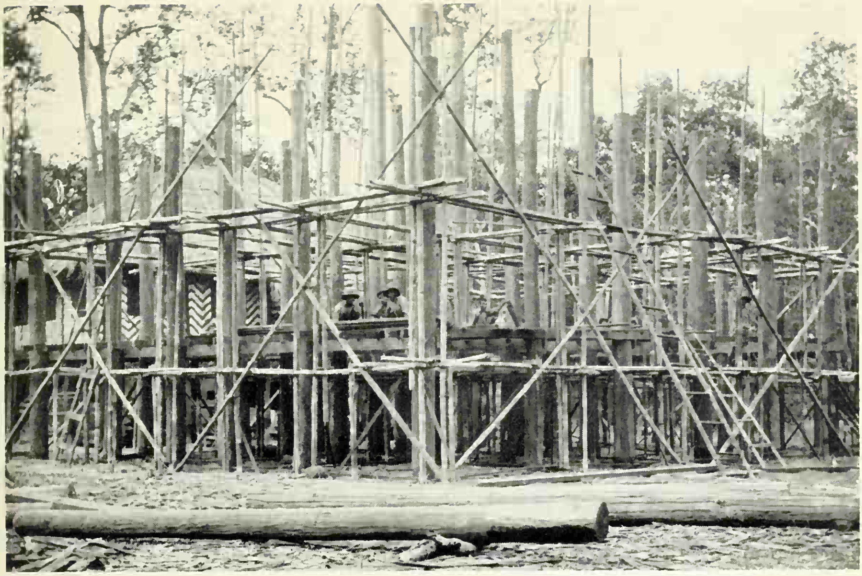
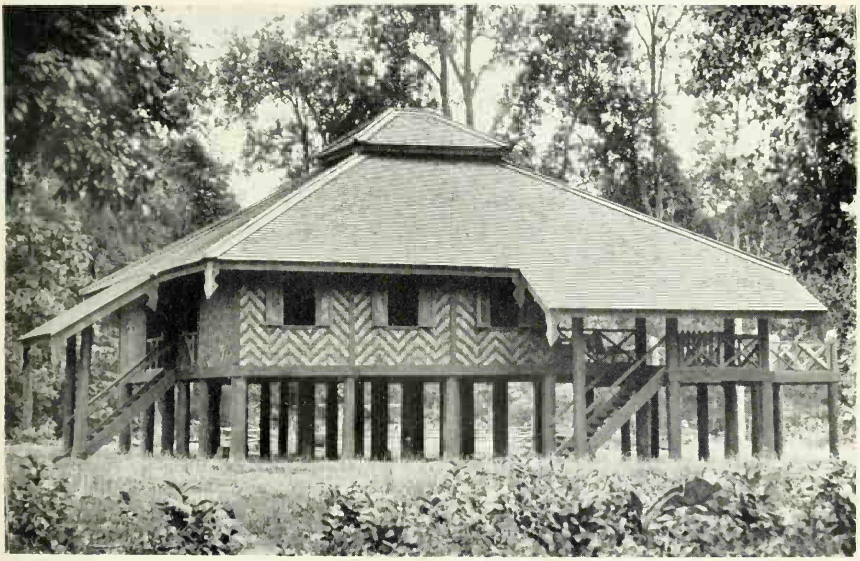

COOK-HOUSE
LATRINE
(Scale 1" = 8 feet.)
4"x2"
3"x2"
5"x2"
4"x2"
5" × 2"
10'
8'
3'
Section
Plan.
10'x10'
3'x2'
3'x2'
3'x6'
4"x2"
4"x2"
4"x2"
6'
8'
1" Plank.
5"x2"
4"x2"
3'
Section
3'
Plan
6'x6'
2½'x6'
References
Roofing. 24 B.W.G. Corrugated Iron.
Posts. 9" Diameter pyinkado.
Walling. Bamboo mat.
Doors & Windows. Wood battens.

FIG. 22





IV. (*a*) A forest rest-house under construction.

(*b*) The completed building four months later.

same for all classes of forest rest-houses. The floor of the cook-house is usually of rammed earth, but a floor of lime concrete 6 inches thick should be laid if possible, as this enables the cook-house to be kept clean. A raised box about 3 feet square filled with sand is sometimes used as a fireplace, but the fire is often simply made on the ground about 2 feet away from the wall, which should be of corrugated iron on the side nearest to the fire. The roof is of corrugated iron or sometimes of boards or shingles, and is fitted with a ventilator, as shown, which allows the smoke to escape. Two broad shelves should also be fitted in the cook-house.

The servants' quarters for a typical rest-house is a two-roomed frame building of timber with bamboo mat-walling. The standard size of each room is 16 feet long by 8 feet wide. The flooring of 1-inch planking should be raised at least 2 feet from the ground. Two battened windows, 2 feet by 3 feet, and a door 3 feet by 6½ feet, are provided for each of the two rooms, which are separated from each other by a bamboo mat-partition down the middle of the building.

The stables are also made of bamboo mat-walling supported on timber posts. The back and sides of the building are enclosed and the front of the building is left open. Mat-wall partitions are erected across the building 8 feet apart to divide the stables into separate stalls. The width of the building is 8 feet, and the length will of course depend on the number of stalls or sections required. The end section is usually enclosed to form quarters for the groom and is fitted with a wooden floor. For the stalls, a floor of lime concrete, 6 inches thick, should be provided if possible. The general construction of the stables and the servants' quarters is very simple and is similar to the other forest buildings, details of which can be seen in figs. 22 to 25 so drawings of these buildings have not been given.

The siting of a forest rest-house and the positions of the various aceessory buildings have often to conform to the contour of the ground, but on level ground the cook-house should be directly behind the main building at a distance of about 20 yards. The servants' quarters should be situated beyond the cook-house, and to secure quiet should not be too near the main building. The latrine should also be situated behind the main building, but as far as possible from the servants' quarters, and must not be near the well.

Plans for a Ranger's quarters are shown in fig. 23. This is the type at present used in most parts of Burma. A cook-house is connected to the main building by a raised and covered passage, as shown in the plan. A small change in the arrangement of the interior walling has been made from the original design to allow for a second small

bedroom and a bathroom in the main building, as this is preferred by most Rangers. The walls of the office-room are made of strong wood planking, and the windows are fitted with iron bars as a protection against theft.

Fig. 24 shows a typical design for a Forester's quarters. It will be seen that the back verandah is enclosed to form a store-room, and also that the staircases are made parallel to the sides of the building. This arrangement keeps the stairs under the cover of the roof, which is a great advantage during the rainy season. A photograph of a Forester's quarters of the same design and construction is shown on plate III. A cook-house and covered passage-way, of a similar type to that shown for the Ranger's quarters, is now often added to a Forester's quarters.

The specifications for the above buildings require posts of 9-inch or 12-inch diameter, walls of single bamboo matting, and flooring of 1-inch planking. The doors and windows are battened and framed, and the roof is of thatch or of wooden shingles. For the main buildings the size of the girders, hip-rafters, and ridge-pieces is 7×3 inches; the post-plates and principal rafters, 6×3 inches; the floor-joists and jack-rafters, 5×2 inches; and the purlins, 4×2 inches. Other dimensions are shown in fig. 25.

The materials used and the methods of construction are practically the same for all the plans shown. The actual erection of the buildings is simple and can be carried out by any village carpenter. In Burma, forest buildings are nearly always erected by contract, and it is usually the Ranger's duty to check the contractor's work with the plans and specifications given.

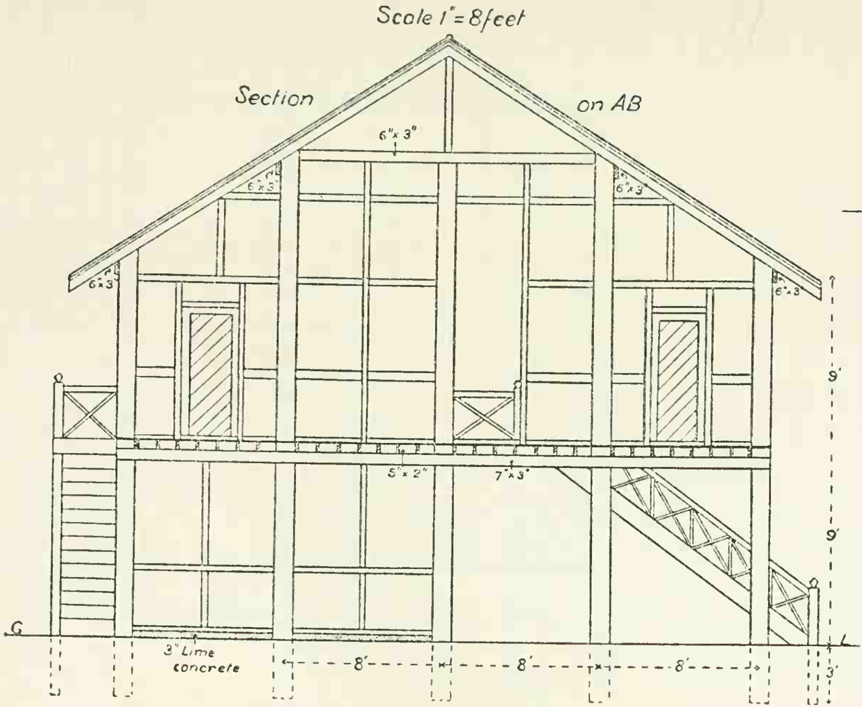
We shall now discuss the various parts of a typical forest building in detail, so that the construction of any buildings of a type similar to the above will be understood.

3. FOUNDATIONS AND HOUSEPOSTS

Timber and bamboo structures of the type described above are so light in weight that no special masonry or concrete foundations are required, and on ordinary soils the buildings are erected on posts sunk 3 feet into the ground.

For main forest buildings in Burma the houseposts are made sufficiently long to raise the flooring to a height of 8 to 9 feet from the ground. If the posts are pointed, and driven into the ground from above by means of a falling weight, they are known as piles. The operation of pile-driving is described in connexion with bridges in

RANGERS' QUARTERS



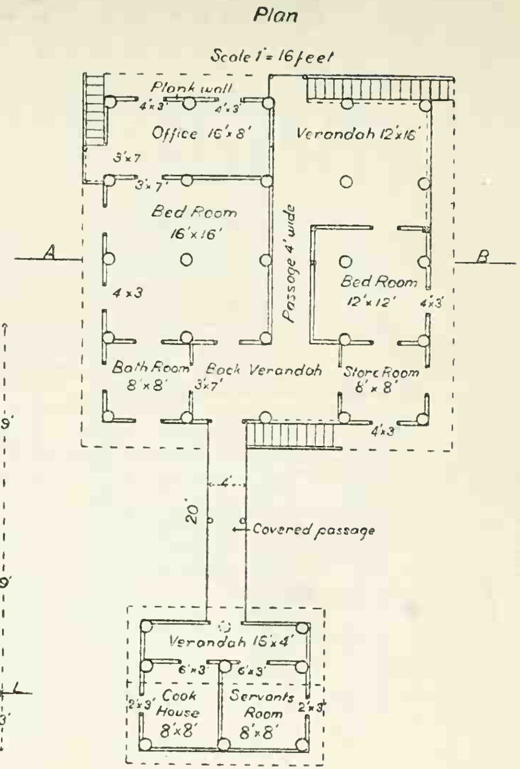


Fig. 23

FORESTERS' QUARTERS

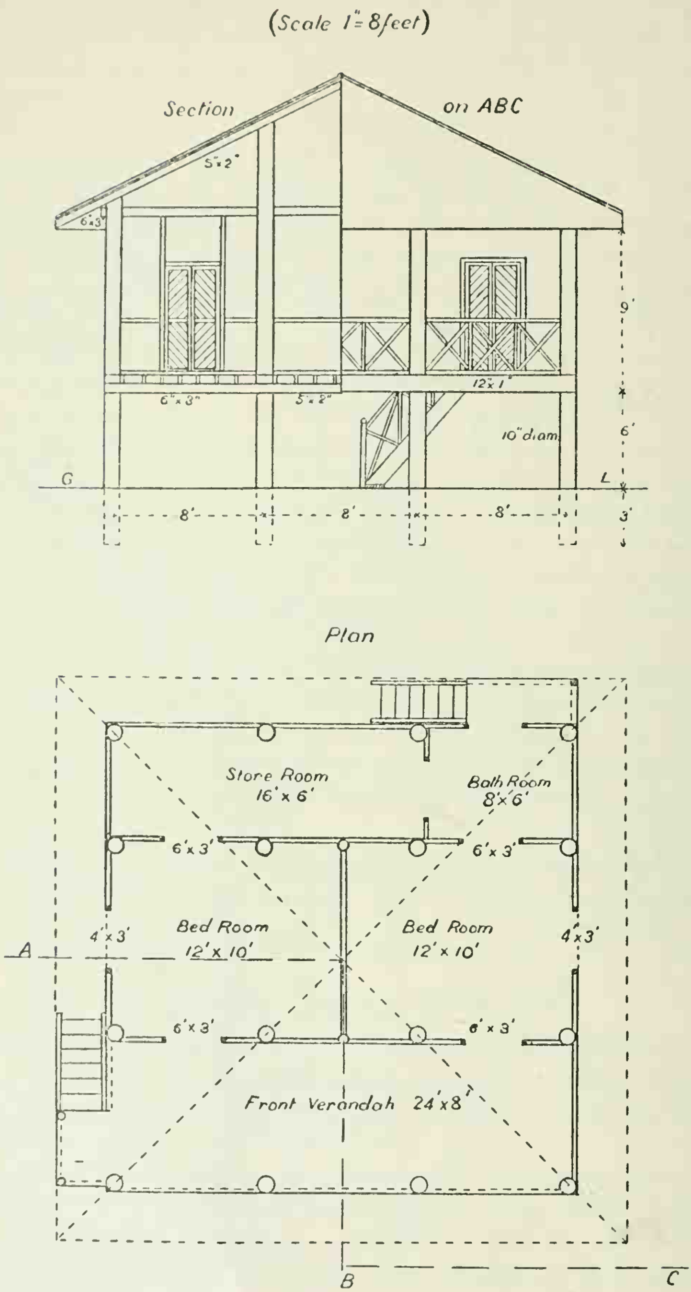


Fig. 24

a later chapter. Piles of the length required for houseposts are hard to drive, and if shorter piles are used the splicing or joining to the houseposts is difficult and expensive. Except in very soft and marshy ground it is unnecessary to use piles for ordinary forest buildings, and the posts are simply erected in holes dug at least 3 feet deep.

The ends of the posts which are to be inserted in the ground must be charred or tarred from the base to a height of 2 feet above ground level, all bark and sapwood being first removed. On hillsides care should be taken to see that the posts are sunk into the original ground and not into soil which has been built up, as this may get washed away in course of time. If the slope is steep the ground should first be levelled off in a series of steps, and different lengths of houseposts used accordingly.

In unstable or slightly marshy ground it is often advisable to attach footings to the houseposts in the form of two short planks, about 10 inches wide and 3 feet in length, spiked or mortised to the ends of the posts and at right angles to each other. A still firmer foundation may be obtained by mortising the posts to sills or wooden bedplates running along each line of posts, but this is very rarely necessary for forest buildings. Where stone is available a large flat stone is often placed under each post, and the space around the post filled with broken stones as a protection against rot. For more permanent buildings in head-quarters the posts are usually bolted to iron footings sunk into concrete or brick 'plinths', which are built up to a height of 2 feet or more above the ground, and thus protect the post from decay and from insect attack.

The felling of the necessary timber and the hauling of the posts to the site should be carried out several months before it is intended to start the erection of the building, so that the sapwood can be removed and posts prepared to save delay when the carpenters arrive.

The outline of the building is first marked out by pegs and the diagonals must always be carefully checked as, if they are not equal, the building will not be truly rectangular.

4. WALLING

As mentioned above, the walls of most forest buildings in Burma are made of split bamboos interlaced to form matting, but where cheap sawn timber is available, subordinates' quarters are often constructed with wooden walls in the form of planking or weather boarding.

Bamboo mat-walling. The method of splitting and weaving

bamboo matting is shown in the photograph on plate II. Good quality matting of this kind should last for ten to fifteen years if earth-oiled each year and kept in proper repair.

The framing for mat-walling consists of 4 inch × 3 inch, or 3 inch × 3 inch scantlings. The bamboo matting is laid over the framing and secured by covering strips, called *zalees*, of 4 inch × ½ inch boarding as shown in fig. 25. The framing also serves for window and door frames, as shown in the drawing. Sometimes 4 inch × 1 inch boarding is placed at 3-feet intervals to stiffen the mat-walling if the main framing is too widely spaced.

Double mat-walling with matting on each side of the frame is objectionable, as the space between the matting forms a breeding-place for rats, but when single matting is insufficient two thicknesses of matting should be placed close together on the same side of the frame.

Flush boarding. The cheapest form of wood walling is made of ½-inch or ¾-inch boarding, usually placed vertically, with either re-bated, or tongued-and-grooved joints; or with butt-joints closed on the outside with laths or small battens 2 inches wide. The boarding is nailed, by 1½-inch nails, to a light framework of scantling, generally 4 inches by 3 inches, or 3 inches square, which is placed horizontally at 3-feet centres, and attached directly to the main houseposts. The boarding should be sawn of such a length that all joints will occur alternately, and also immediately over a point of support. This type of walling is generally used for interior walls or partitions.

Weather boarding. A good weather-proof wood walling is made by ½-inch or 1 inch planks about 8 inches wide laid horizontally, with an overlap of 1½ inches. The planking is nailed to vertical battens, 4 inches by 3 inches, placed 3 to 6 feet apart. Vertical covering strips, 4 inches by 1½ inches, notched to fit the overlap of the planking, are generally used at the corners of the building, and are fastened by screws through the planks to the scantlings, but these are sometimes omitted in rough forest work. Proper weather boarding is usually cut tapering in cross-section, and the thicker edge or butt is placed downwards. There are also several other forms of weather boarding, but for forest work plain planking is all that is usually available.

Trellis work. This is used to form a protective walling in places where it is not desired to exclude light and air, such as in the upper part of the interior walling of a forest rest-house. It is usually made of teak battens 1½ inches by ½ inch, crossed diagonally and sloping at an angle of 45°; the spaces being 1½ inches square. The battens should be secured at the ends by 1½-inch wire nails, and also nailed

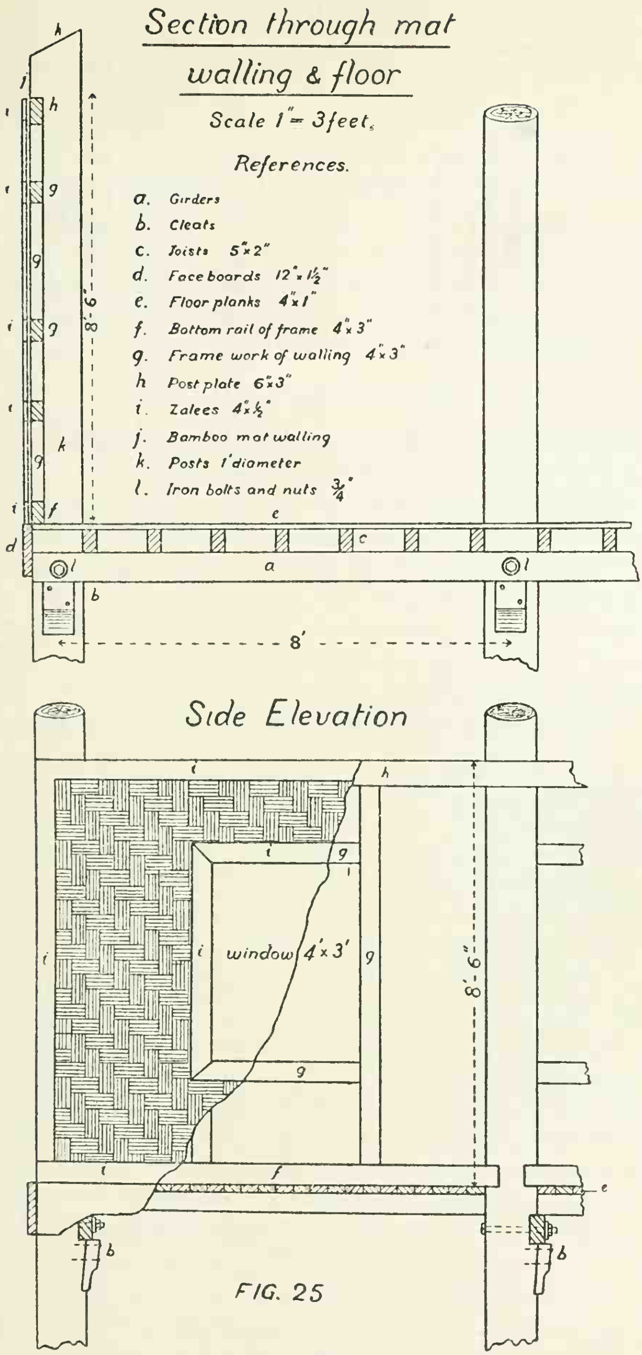

Section through mat walling & floor
Scale 1" = 3 feet.
References.
a. Girders
b. Cleats
c. Joists 5"×2"
d. Face boards 12"×1½"
e. Floor planks 4"×1"
f. Bottom rail of frame 4"×3"
g. Frame work of walling 4"×3"
h. Post plate 6"×3"
i. Zalees 4"×½"
j. Bamboo mat walling
k. Posts 1' diameter
l. Iron bolts and nuts ¾"
8'-6"
8'
Side Elevation
window 4'×3'
8'-6"

FIG. 25

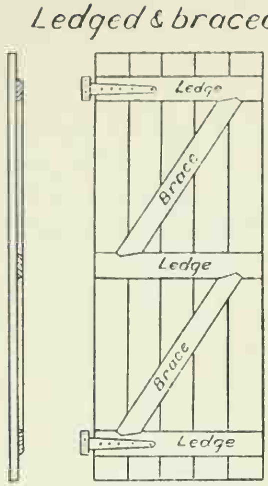


FIG. 26

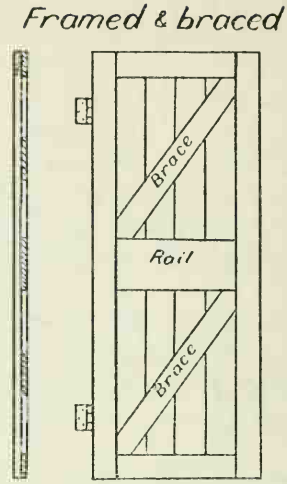


FIG. 26 A

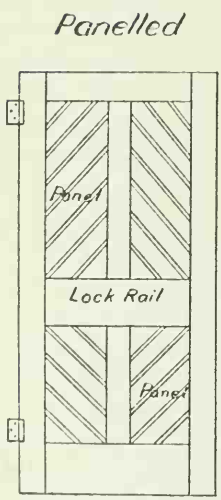


FIG. 27

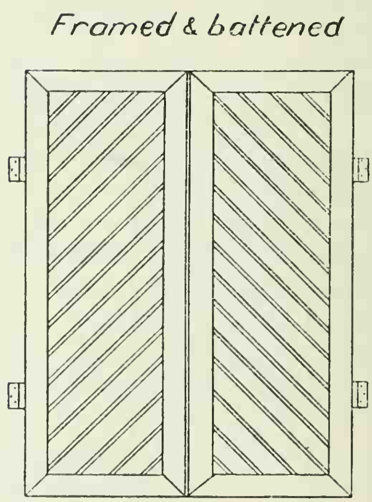


FIG. 28

to each other at intervals of 3 feet. The edges of the work should be finished off with a batten all round on both sides.

Corrugated iron walling. This is sometimes used for cook-houses and latrines. Sheeting of 22 to 26 gauge is commonly used. It is screwed to a framework of 3-inch by 3-inch scantlings, with galvanized iron screws 2 inches long, a lead washer being used under each head. The side overlap should be one corrugation, and the end overlap at least 3 inches. Corrugated iron walling keeps out rain and is fairly cheap and durable, but it is not suitable for a rest-house as it makes the rooms very hot in the day and cold at night.

5. DOORS AND WINDOWS

Doors. The ordinary type of door used in forest buildings is 7 feet high by 3 to 4 feet wide. Doors 3 feet wide and over should be hung in two equal portions or 'leaves', as shown in fig. 28, as this form of door is lighter, gives less strain on the door-frame, and takes up less space when the door is opened. The door-frame consists of two posts, which are tenoned or jointed at the top into a horizontal piece of timber which forms the 'lintel' or top sill, and are joined at their lower ends or feet to another horizontal piece which is called the ground sill. In forest buildings the posts are often extended up to the post-plate, and form part of the framework to which the bamboo walling is attached.

A rebate is usually cut round the inside of the posts and lintel, and the door fits into this rebate when shut. The width of the rebate should be the same as the thickness of the door, and the depth is usually about $\frac{1}{2}$ inch. In forest buildings the rebate is often formed by nailing a piece of $\frac{1}{2}$-inch boarding round the inside of the frame. Doors should always be arranged to open inwards to a room so as to hide as much as possible of the room when the door is partly open.

The types of doors most commonly used are: the ledged and braced door (fig. 26), the framed and braced door (fig. 26 A), and the panelled door (fig. 27). The first two types are also called 'battened' doors. Their construction is simple and can be seen from the drawings.

The timber used for doors should be narrow in order to lessen the effects of subsequent shrinking, as thoroughly seasoned timber is usually difficult to obtain. The planks or battens may be rebated, or tongued and grooved together. For the sake of appearances, a beaded edge is often given to the tongued and grooved planking, so that any opening out of the joints will not be noticeable.

In the case of braced doors it is very important to see that the braces slope upwards and outwards from the hinged sides as shown

in the drawings. Doors are frequently seen where the hinges have been placed on the wrong edge of the door, and the bracing is then practically useless.

A panelled door has a better appearance but is more expensive than a braced door. The framing is mortised and tenoned together, and grooved on the inner side to receive the panels. Ordinary panelled doors have four panels. In doors of good quality each panel is made of one piece of selected and seasoned wood, but in cheaper doors the panels are often made of narrow battens of tongued and grooved planking, fitted together at an angle of 45° with the door-frame, as shown in fig. 27.

A framed and battened door is commonly used in forest buildings. It consists of a plain frame of 4-inch × 1-inch timber, over which 4-inch × $\frac{1}{2}$-inch tongued and grooved battens are nailed in a slanting direction, as in fig. 28. The door is generally finished off with a second light frame placed over the battens, and this greatly adds to its appearance.

The best door-fastenings for forest buildings are sliding wooden latches resting in brackets and fitted with small knobs for handles, and to secure the door from the inside iron drop bolts should be attached to the top and bottom of the door fitting into holes cut into the door-sills. Similar fastenings are suitable for the windows. Wooden cleats should be made for holding the windows and doors firmly open when required, without swinging. Iron hinges should be used in preference to japanned-metal hinges as they are more durable. For ordinary doors 4-inch or 5-inch butt-hinges, spaced 3 feet apart, are sufficient. For windows the hinges may be from 3 inches to 4 inches wide and spaced about 2 feet apart.

Doors are usually bought at a fixed rate per square foot. A good teak panelled door, complete with iron fittings, may cost about Rs. 1/12/- per square foot, and a teak framed and battened door about Rs. 1/2/- per square foot. The cheapest form of door is made of bamboo matting fitted on a wooden frame, in the same way as for mat-walling. Two thicknesses of mat are generally used.

Windows. The usual size of windows or shutters used for forest buildings is 4 feet by 3 feet. They are hinged vertically, and are made in two leaves in the same way as doors. The rebate should always be cut on the outer side of the window-frame and the windows should open outwards. The window-frame is formed by the scantling of the wall framework, as shown in fig. 25. The windows are usually made either of bamboo matting attached to a light frame, or of wood battens similar to the doors. Glazed windows are expensive, and are rarely used for forest buildings except in head-quarters.

Windows and doors fitted with movable venctian shutters are sometimes used in permanent buildings and rest-houses. These shutters can only be made by skilled carpenters and are expensive, but are useful in special cases where ventilation is required without admitting the glare of the sun. All doors and windows must be carefully hung so as to move freely and fit accurately. Iron fastenings and handles are frequently stolen from buildings in the forests, and simple contrivances and fastenings which can be made locally are preferable.

6. FLOORS AND SIMPLE STAIRS

Wooden floors. The specification for floors in the standard plans for forest rest-houses and Subordinates' quarters in Burma require tongued and grooved flooring; but this is not often available, and ordinary 1-inch boarding with butt-joints is commonly used in practice. The narrower the planking the less the subsequent opening up of the joints through shrinkage, and the best width is about 4 inches. When laying the flooring the boards should be tightly cramped together with a carpenter's cramp before being nailed to the joists.

The joists are 5-inch by 2-inch scantlings, placed about 15 inches apart from centre to centre, as shown in fig. 25. They are supported by girders, 7 inches by 3 inches, which are bolted directly to the house-posts. The posts, which are one foot in diameter, are notched about $1\frac{1}{2}$ inches deep to receive the girders; and cleats, which are spiked to the posts, should be added to give additional support to the girders, as shown in the drawing. Slight notches should be made in the posts to receive the lower part of the cleats, as shown in the drawing; this is called 'housing' the cleats.

It will be seen from the drawings of forest buildings in figs. 21 to 25 that the distance between the girders is only 8 feet in each case. If a building has to be constructed in which the distance between the floor-joist supports is greater than 8 feet, the joists must be strutted apart, to prevent them from twisting and to give them stiffness. The best arrangement of strutting is a double row of short 3-inch by $1\frac{1}{2}$-inch battens crossing diagonally from near the top and bottom edges of each pair of joists. They are nailed at the crossing to each other, and at their ends to the joists. This method is known as 'herring-bone' strutting.

Where tongued and grooved flooring is used the nails should be driven at an angle through the tongued edge of the planks, entering the planks just above the tongue, as already shown in fig. 20. This is

called 'hidden nailing', as the heads of the nails are covered by the upper edge of the adjoining boards.

Ground floors. These may be made of bricks, stone, concrete, or simply of rammed earth or laterite. The preparation of the surface is the same in each case. Layers of earth should first be put down and each layer well watered and rammed until thoroughly consolidated. If a brick or concrete floor is to be laid a sufficient quantity of the earth filling should then be removed and levelled down to make room for the floor. The prepared surface should be finally rammed and consolidated before the floor is laid.

Brick flooring. On the surface prepared as indicated above a layer of dry sand, 3 inches deep, should first be spread as a protection against damp and white ants, care being taken to use really pure sand and not sandy earth, in which white ants flourish. On the sand is laid a course of lime concrete, about 3 inches thick and well rammed. The bricks are then bedded on the concrete in lime mortar. The joints between the bricks must be made fine. They should not exceed about $\frac{1}{16}$-inch in thickness, and the sides of the bricks must be rubbed if necessary to give fine joints. For floors on which heavy weights are likely to be placed it is advisable to add a second course of bricks placed on edge. These must be specially well-shaped and smooth bricks, so that they can be laid quite close to each other with merely a thin joint of the finest cement or lime mortar between them.

Concrete flooring. For seed store-rooms where a floor which can be kept clean and free from insects is required, and also for the ground floors in Rangers' quarters, a concrete floor is often used. The ground surface should first be prepared as above and the concrete then laid in two layers. In the lower layer the aggregate is usually made coarser than in the upper layer, and a final surfacing of cement is often added. To avoid danger from subsequent cracking a concrete floor is usually laid in squares with expansion joints between. Yellow arsenic is often mixed with the concrete to keep out white ants from the building; 4 lb. of arsenic is sufficient for 100 cubic feet of concrete or masonry. Arsenic should not be used in the surface layer of a floor, as the dust is poisonous.

Wooden stairs. For forest buildings, only simple wooden stairs are required, but these are often badly designed and constructed. Before discussing the construction it is necessary to explain a few of the special carpentry terms which are given to various parts.

The 'tread' is the horizontal upper surface of the step upon which the foot is placed. The 'rise' is the vertical height between two treads, and the 'riser' is the front face or vertical piece of timber

which gives solidity to a step but is usually omitted in open stairs. The 'nosing' is the outer edge of the tread and in most cases it projects beyond the face of the riser and is rounded off. The 'strings' are the two inclined planks to which the ends of the steps are fastened and by which they are supported. A 'flight' is a continuous series of steps. Not more than eighteen steps should be made in any one flight without a flat platform or 'landing'.

The angle of ascent will depend on the total height to be reached and the amount of floor-space available in the plan. For ordinary wooden steps the rise should be about 8 inches, while the tread should not be more than 12 inches wide nor less than 9 inches. The strings are usually formed of $3\frac{1}{2}$-inch planking, 10 to 12 inches wide, with mortises cut about $1\frac{1}{2}$ inches deep, into which the treads are fitted as tenons. Two long wrought-iron bolts, $\frac{3}{4}$ inch in diameter, should be fitted across each flight of stairs near the top and bottom to hold the strings firmly together, and two of the steps are often made with long tenons which go completely through the strings to make the frame more rigid. The lower ends of the strings must be notched or tenoned to a trimmer 2 feet wide to give a firm footing. A simpler form of steps may be made by notching the upper edges of the strings to receive the whole width of the treads, but this weakens the strings and should only be used where the strings are supported by a wall or for short flights.

A handrail should always be provided running parallel to the inclination of the stairs and at a height of about 2 feet 8 inches, measured vertically above the line of nosing.

7. ROOF CONSTRUCTION

There are many elaborate forms of iron and timber-frame structures used for the support of various types of roof coverings on large buildings, but we shall only deal here with the simpler roofs used in forest work.

The slope of a roof is called the 'pitch', and is measured by the angle the roof makes with the horizontal, or sometimes as the ratio of the height of the roof at its centre to its span. The pitch varies with the kind of roofing material used; for corrugated iron roofs it may be only 12 degrees, but for thatch roofs it should never be less than 35 degrees.

Common roof-trusses. The supporting structure or framework of a roof is called a 'truss'. The form of truss used depends upon the span and on the weight of the roofing it has to support.

(*a*) **Lean-to roof** (fig. 29 *a*). This is the simplest type of roof and is used chiefly for wooden huts and sheds of small span, and for verandahs constructed against a wall or main building. The rafters are notched or spiked directly to the wall-plates or post-plates. The roof consists of a single sloping surface.

(*b*) **Couple roofs** (fig. 29 *b*). In this case the rafters are used in pairs or couples, one from either wall. They are secured by spiking their upper ends to a ridge-piece, the lower ends being notched or nailed to the post-plates.

(*c*) **Collar roof** (fig. 29 *c*). When the span is greater than 12 feet the rafters need tying together to save the outward thrust of the weight of the roof against the walls. The tie in this case is placed half-way up the rafters and is known as a 'collar'. It has the advantage of allowing plenty of head-room in small buildings, and is very commonly used in forest huts and shelters.

(*d*) **Couple-close** (fig. 29 *d*). When the feet of a pair of rafters are tied together horizontally they are said to be 'closed' and the arrangement of timbers is known as a 'couple-close'. In many buildings the rafters are tied together at the height of the post-plates and form joists to which a ceiling may be attached. In long spans from 16 to 18 feet, or if ceilings are attached, the ties need to be supported at their centres by iron rods, as in fig. 29 *e*.

The above roofs are 'single-raftered' roofs, as the roof covering is fixed directly to the rafters, but for spans of 18 feet and upwards it is better to use main trusses or principals, which are usually erected at intervals of from 8 to 10 feet and connected together by horizontal scantlings called 'purlins', which support the smaller or common rafters to which the roof covering is attached. The two forms of main trusses most commonly used are the King-post Truss and the Queen-post Truss.

King-post truss. A detailed elevation of a king-post truss is shown in fig. 30. It will be seen that the truss is composed of principal rafters, tie-beam, king-post, and struts. The details of the carpentry joints in this truss have been dealt with in a previous chapter.

The advantage of this form of trussing is that the weight of the roof is carried vertically on the walls or posts and no outward thrusting stress is produced. Between the trusses are carried the ridge-piece and purlins, and to these are fixed the common rafters, which in their turn carry the roof covering. Thus the weight is carried first by the common rafters to the ridge-piece, purlins, and post-plates; and by them is carried to their junction with the main roof-trusses. These principal trusses are sometimes supported directly on the main house

LINE DIAGRAMS OF ROOF-TRUSSES

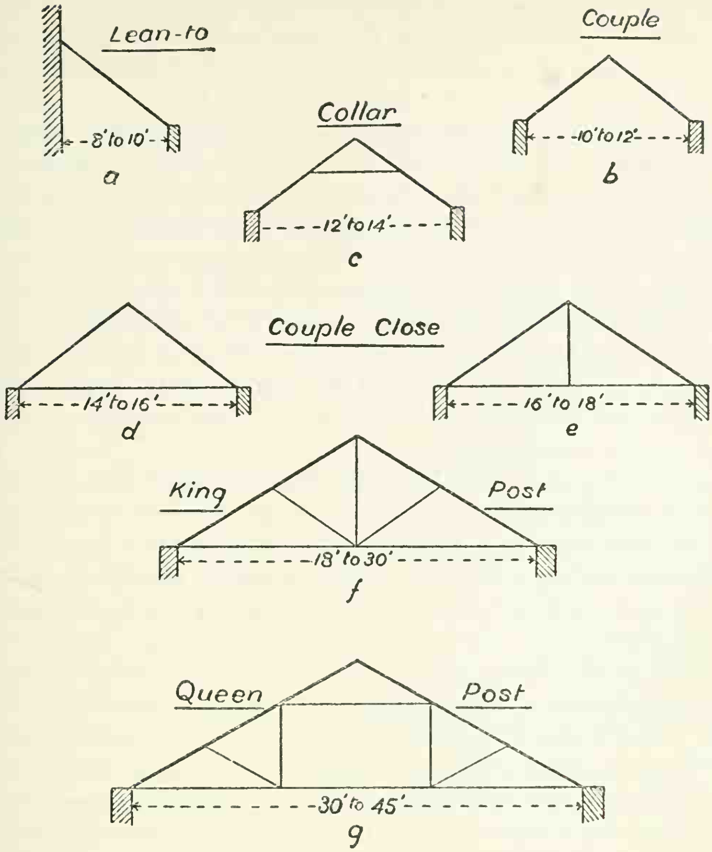


FIG. 29

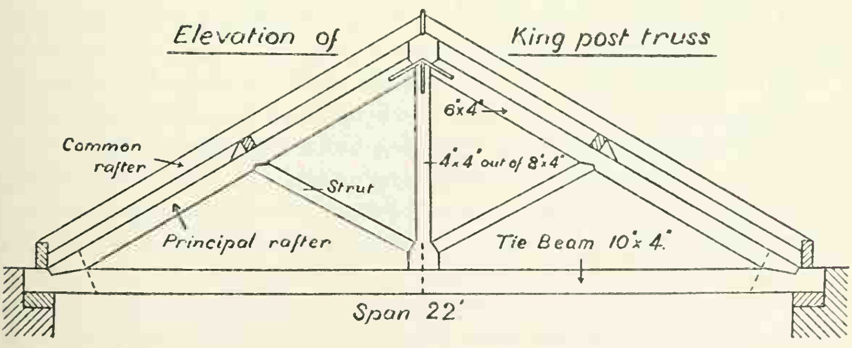


FIG. 30

posts which are placed at suitable intervals apart. In fig. 30 only one row of purlins is shown above the principal rafters on each side, but on larger roofs there are usually several rows. Small cleats should always be placed below the purlins as shown.

It should be noted that both the tie-beam and the king-post are in tension and not under compression like the struts. The king-posts are often cut slightly short, so that when the bolts and joints are tightened a slight camber is given to the tie-beam, which allows for subsequent settling, and thus avoids any sagging in the centre.

Queen-post truss (fig. 29 *g*). When the span exceeds 30 feet, two vertical posts are generally used instead of one; these posts are known as 'queens' and the whole is called a 'queen-post' truss. A queen-post truss can be used for spans up to 45 feet, but most trusses of over 30 feet are now constructed with iron rods, and a timber queen-post is rarely used.

Composite trusses with the tension members of steel and the compression members of timber are now very common, but are not often used in forest buildings. One objection to their use is that very careful construction of the joints is necessary owing to the difference between timber and steel in expansion and contraction under changes of temperature.

Gable roof. When a roof is finished off vertically at the ends it is called a 'gable' roof. The end walls are continued up to the ridge piece, and thus fill in the triangular space between the two roof slopes and the post-plate. The eaves are usually constructed to overhang a little beyond the end walls, and a small opening is often left just below the ridge for ventilation purposes. Fascia-boards are fitted along the eaves of a gabled roof to prevent wind from getting under the roof covering and also to improve the appearance.

Hipped roof. In the forest buildings shown in figs. 21, 23, and 24, the ends of the roof are terminated by slopes, and this form of structure is called a 'hipped roof'. Both ends are hipped, forming four sloping surfaces. If the building is square, all four slopes will meet at a point and they will all be triangles, but if the building is not square only two of the slopes will be triangles and the other two will meet in a ridge, each of them being in the form of a trapezium. The length of the ridge will be found by subtracting the breadth of the building from its length.

The ridge-piece may be supported directly on two or more main house-posts, which run right through the building; but as already mentioned it is often desired to form a passage down the middle of the building in order to make the rooms on both sides equal in size.

Two rows of house-posts are then necessary at a distance apart equal to the width of the required passage. The tops of each pair of house-posts are connected by a simple truss, and these trusses support the ridge-piece.

The main rafters which join the ridge-piece to the corners of the building are called 'hip' rafters. From these hip-rafters are supported smaller 'jack' rafters, the lower ends of which are supported by the post-plates. The jack-rafters are placed in pairs, as shown in fig. 31, becoming shorter as they approach the corner of the building.

A hipped roof is easy to construct, and the shape protects it from damage by wind, but it allows of no ventilation unless a separate ventilator is fitted over the ridge, and this is very difficult when the roof is thatched.

8. ROOF COVERINGS

The roof coverings most commonly used in forest work are bamboo, thatch, shingles, corrugated iron, and wooden boarding.

Bamboo roofing. Rafters and purlins of bamboo are used to support thatch roofing, as will be explained later, but bamboo is also often used instead of thatch to form the entire roof covering. The most common form of bamboo roof covering is made of flat woven strips of split bamboo. This form of roofing is called *wagat* in Burma. The bamboos are first split into short pieces about one foot long, which are interwoven with four longer bamboo strips to form a narrow sheet or section about 6 feet long and one foot wide. The method of splitting and weaving is shown in the photograph on plate II. The sections thus made are placed horizontally on the roof, overlapping each other like tiles, and are tied directly to the rafters. To ensure sufficient overlap to make the roof watertight, each row of sections should be placed only 2 inches higher than the last row, and the ends of the sections should overlap each other by at least 6 inches. This form of roofing should last about four years, and can be made much more durable if the sections are boiled in crude oil before use, and then given a coating of crude oil annually. The bamboo strips tend to shrink during the hot weather, and this sometimes allows water to leak through at the beginning of the rainy season. Also, unless the roof is carefully constructed the sun will penetrate obliquely through the joints between the strips.

Another form of bamboo-roofing is made with long straight bamboos of large size, split in halves longitudinally. The split halves are placed side by side, alternate pieces being placed with their convex

surfaces upwards so that their outside edges fit in the grooves formed by the two adjoining pieces, as in a pantile roof. This method is chiefly used in Karen villages, and is only practicable where the roof consists of a single sloping surface, as in fig. 29 *a*. Unless the bamboos are thoroughly dry before splitting, the split pieces warp and twist leaving open gaps in the roofing.

Thatched roofing. This type of roofing is very commonly used as it is cheap, cool, light, and easy to construct. It is not very durable and is highly combustible, and because of the danger from fire there are local orders prohibiting its use in large towns. It harbours insects and rats, and needs frequent repair and replacement. The pitch of a thatched roof should be about 35 degrees.

For very light thatch roofs the rafters may consist of whole bamboos placed 9 inches apart, with horizontal ties of single bamboos at intervals of 2 to 3 feet; and this type of roof is commonly used for temporary buildings. Timber rafters and purlins, where available, should be used for permanent buildings, with whole bamboos, or *achinwa*, laid over the purlins about 8 inches apart.

As already mentioned in Chapter I, under 'Materials used for construction', the thatch most commonly used in Burma is made from *Imperata arundinaceae*, which is a long coarse grass found in most parts of the country. The blades of grass are folded double over a bamboo stick, and assembled and tied to form a strip or section nearly 7 feet long. The breadth of the section or *byit* varies with the quality of the grass. The best grass will form a section almost 3 feet wide. See the photograph on plate III.

The sections are tied horizontally at intervals of 2 inches, commencing from the bottom as shown. The overlap at the ends should be at least 6 inches. Long strips of split bamboo are placed over the thatch, and tied through it to the rafters by cane ties to prevent it from being blown off by wind. The ridges and the hips should be thatched with great care, as these are the places where leakage first occurs. All bamboos used for rafters should be seasoned by soaking in water for ten days and care should be taken to see that no old bamboos containing borers are used when a building is re-roofed.

In India the thatch is usually first made up complete on a lattice-frame on the ground; and there are several other methods of construction which are known to the local villagers and need not be described here.

The number of sections required for the roof of an ordinary forest rest-house can be roughly estimated by multiplying the basal area of the building in square feet by $1\frac{3}{5}$. A thatched roof should last

Rafters for Hip roof

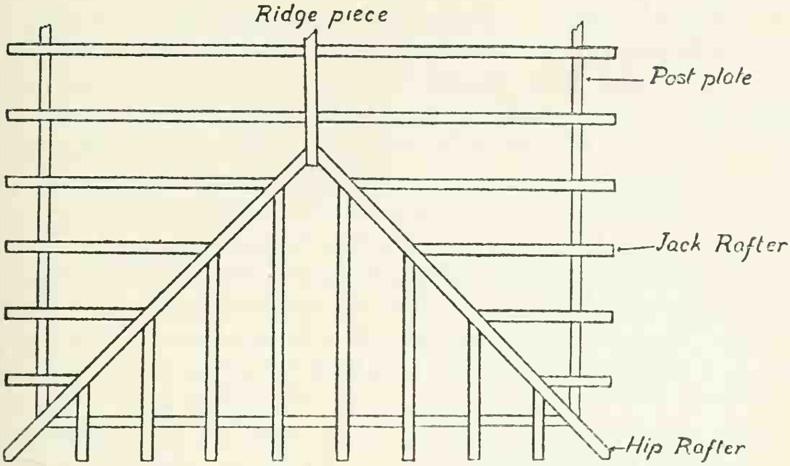


FIG. 31

Ventilator for Corrugated Iron Roof

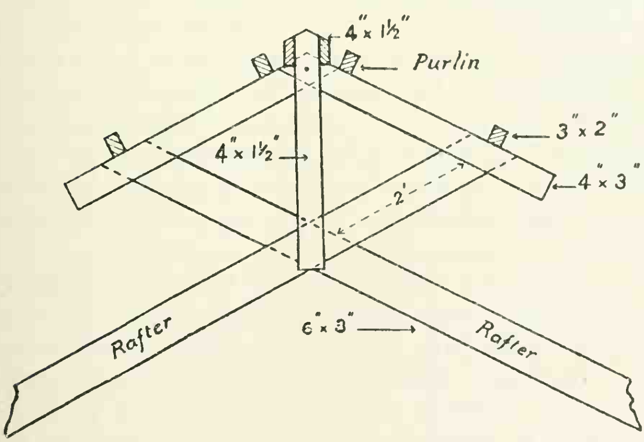


FIG. 32

from three to five years, but the ridges and hips usually require replacement every year. Owing to the danger from fire no thatch or bamboo rubbish from the roof should be left within fifty yards of the building.

Palm-leaf thatch. Thatching with palm-leaves is still very common in most tropical countries. As already mentioned in Chapter I, the *dani* palm (*Nipa fruticans*) and *salu* (*Licuala peltata*) are two of the palms most commonly used in Burma, and form a very cheap roof covering for temporary buildings. The leaves are stripped from the stems, doubled over a bamboo stick, and stitched together with thin strips of bamboo to form long sections. These sections are about the same size as the grass sections described above, and are fastened directly to the rafters in a similar manner. Palm-leaf thatch is very liable to damage by wind, and in exposed situations a close lattice-work of bamboo, in squares about 4 inches wide, is often placed over the surface of the thatch in addition to the ordinary bamboo wind-ties. Where palm-leaves are not available, large leaves from various species of broadleaved trees, such as *In* (*Dipterocarpus tuberculatus*), are frequently used for the roofing of temporary forest buildings.

Shingle roofing. Shingle roofs are more durable than thatch. They lessen the danger from fire and are also cleaner in use. As shingles do not require renewal so frequently as thatch the cost of shingle roofing over a number of years is often less than the cost of thatch. The roofs are not so cool as thatched roofs and they require careful construction to avoid leakages. The shingles are nailed to small wooden battens placed horizontally. If the main rafters are spaced wide apart it is necessary to use purlins with common rafters above, spaced from 2 to 3 feet apart, to support the battens, but in most forest buildings the battens are nailed directly to the main rafters. The battens should be of good quality timber, size 2 inches by 1 inch, laid on the flat, unplaned, and spaced 5 inches from centre to centre. They should be nailed to the rafters with one 2-inch wire nail at each crossing.

The usual sizes of shingles are 15 inches by 5 inches and 15 inches by 4 inches, the thickness being $\frac{1}{2}$ inch tapering to $\frac{1}{4}$ inch. They must be sound, free from cracks, flaws, or sapwood. Each shingle is nailed to its batten by two $1\frac{1}{4}$-inch nails. The lap of the shingles should be 5 inches. The joints between two overlying shingles must come truly over the centre of the underlying one. Care should be taken not to lay shingles too close or they will rise when expanded with moisture. At the hips, the shingles should be cut truly to line, and

a double thickness must be laid at all ridges and eaves. All shingles should be dipped in boiling oil, as described in Chapter I.

Shingles which crack when being laid must be removed and replaced. The hip and ridge boards should be of good quality timber, 9 inches by 1 inch, and planed and oiled on the exposed face. The joints of the hip and ridge boards should be covered by a properly shaped piece of 4-inch by 3-inch timber, which should be nailed through to the rafter or ridge piece below. The pitch of a shingled roof may be from 26 to 35 degrees.

Corrugated iron roofs. These roofs are easy to construct, very durable and fairly cheap, and they cannot catch fire; but buildings roofed with corrugated iron become very hot, and the noise from rain beating on the iron is unpleasant. Corrugated iron is rolled sheet-iron, bent into a series of parallel ridges and hollows, called corrugations, which add to the stiffness and strength of the sheets. The iron is usually coated with zinc by a special process to prevent it from rusting, and it is then called 'galvanized' iron.

The sheets of galvanized iron vary in length from 6 feet to 10 feet, and in breadth from 2 feet 6 inches to 3 feet. The thickness is measured by gauge numbers as in the case of wire. The larger the gauge number the smaller the thickness of the iron. The usual gauges are 20, 22, and 24, the thicker sheets being of course more durable. The sheets are fastened to purlins which run in horizontal lines along the length of the roof, and must be firmly fixed to the rafters to prevent removal by wind. One line of purlins should be laid at each end, and, if the sheets are long, another line across the middle of the sheets.

The sheets should overlap 6 inches in length, and side-laps should extend over two complete corrugations. They should be fastened to the purlins by $2\frac{1}{2}$ or 3-inch galvanized iron screws, or with hook-bolts. A screw or bolt should be placed in every third corrugation and at all corners and overlaps. The holes for the screws must be punched on the crests of the corrugations and never in the hollows, and should be just big enough to allow for expansion and contraction, but not unnecessarily large. A lead-washer must be fitted under the head of every screw or bolt, which must be properly screwed down to ensure a water-tight joint, the washer being bent to fit the curve of the corrugation. Where possible the screws and bolts should be set in white lead.

Wind-ties of $1\frac{1}{2}$-inch by $\frac{1}{4}$-inch bar iron must be provided near the eaves. These wind-ties run over the corrugations, and are bolted through the sheets to the purlins and the main rafters by $\frac{1}{2}$-inch bolts

at intervals of not more than 4 feet. Slot-holes are cut in the wind-ties where the bolts pass through to allow for contraction and expansion.

The ridges and hips must be covered by galvanized iron capping, screwed down to the purlins or riveted to the corrugated iron sheets. The capping is laid in lengths, with an overlap of at least 9 inches at each joint.

Buildings roofed with corrugated iron may be made cooler by providing a passage for the escape of hot air along the tops of the walls and at the gable ends, and also by making special ventilators in the ridges. Rats and other vermin can be kept out of the building by filling in the ventilation spaces with fine wire netting. Ridge ventilators are often formed by slightly raising and prolonging the ends of several rafters, so that they cross over the ridge board, and then fixing a second tier of corrugated iron to purlins supported on short battens which are spiked to the ends of the rafters, as shown in fig. 32.

A wooden ceiling, or a board lining, fitted below a corrugated iron roof keeps the building cooler, and the outside of the roof or the ceiling is often painted white to lessen the absorption of the heat of the sun. Corrugated iron will last much longer if painted. Another method is to fix a layer of bamboo matting below the purlins.

Plank or board roofing. The boards are laid horizontally, commencing from the lower edge of the roof as in laying shingles. They should be given an overlap of about half their width. A common size of board is ½ inch by 5 inches, overlapping 2½ inches. They are nailed directly to the rafters, two nails being put in at each junction, one of which passes through the overlap of two boards.

Board roofing is very quickly constructed and is often used for the roofs of sawmills and other places where sawn timber is cheap. It may also be used for the roofs of cook-houses if corrugated iron is not available, as boarding is not so inflammable as thatch. A board roof is very rarely water-tight, as the boards soon warp or crack, and water gets through any defects in the timber. It is therefore not so satisfactory as a shingle roof, and should only be used for unimportant buildings.

Sheets of lead and zinc are sometimes employed as a covering for flat roofs. Slates, tiles, sheets made of a composition of asbestos and cement, and special kinds of felt such as Ruberoid, are also used as roofing materials; but these are too expensive for the type of forest buildings dealt with here.

9. THE PREPARATION OF AN ESTIMATE

Estimating is usually treated as a separate subject from engineering, but estimates for forest buildings are often badly prepared, and a few brief notes are given here for reference.

An estimate may be defined as a detailed calculation of the quantities of materials required and expenditure likely to be incurred in the construction of a building or other piece of work. It should consist of a report, specification, details of measurements, and an abstract of cost.

Report. This should show the necessity for, or the object of, the proposed work. It should give a general description of the work, mentioning its exact site and giving any reasons for the type or design adopted.

Specification. The specification should lay down clearly the nature and quality of the work required and of the materials to be employed. Also any special conditions to be observed in the execution of the work. For small forest works the report and specification may often be combined into one.

Details of measurements. These are given in the form of a tabulated list, showing the actual measurements and volume of all materials in all parts of the work in detail. The size should be given and number of parts, and also the total contents in cubic feet. The dimensions are usually obtained from the working drawings, and these details are often of great assistance to a contractor in submitting his tender, as small contractors are often unable to judge quantities or to prepare their own estimates from the drawings alone. The various items should be grouped under separate headings, such as flooring, walling, and roofing. An example is given on page 60 of the actual measurement form and abstract of cost prepared for the forest cook-house shown in fig. 22, but with corrugated-iron walls and concrete flooring.

Abstract of cost. This shows the total quantities of each kind of work and the rate per unit of measurement. The rates should be obtained from a local schedule of rates where possible and, if the current rates are unknown, previous costs of similar work under the same conditions should be taken as a guide. The cost of the materials and the estimated cost of transport to the site should be shown separately. After the total estimated cost has been obtained, an allowance is added for possible contingencies due to changes in design or unforeseen expenditure of any kind. The usual allowance is 5 per cent. of the whole cost, and if it is added to the total no extras for con-

tingencies need be allowed under individual sub-heads. If tenders are called from contractors the abstract of cost is of course retained to compare with the contractor's rates and to act as a check on the tenders.

Working drawings. Plans and sections should be furnished for all important structures showing dimensions to scale, and with sufficient accuracy to admit of the measurements being taken off directly. One inch to 5 feet is a suitable scale. The dimensions should also be fully noted on the drawings, for convenience and for checking. Where important details cannot be shown on the principal drawings they should be shown separately on an enlarged scale.

Measurement of a forest building. In taking out the quantities it is best to follow a definite system in order to prevent omissions, and a good rule is to begin with the foundations and work steadily upwards to the roofing. When dealing with walling, first take all the measurements without regarding any openings for doors and windows, and then deduct these afterwards.

Hipped roofing is the only part of a forest building which presents any difficulty when measuring directly from the drawings. For the surface of the roofing it is best to make two items, 'front and rear' and 'ends'. First the mean length is calculated from the length of the ridge and the length of the eaves; and the breadth is measured from ridge to eaves on the slope; then, twice the mean length multiplied by the breadth equals the combined area of the 'front and rear'. The combined area of the two 'ends' is obtained by multiplying the length of one of the corresponding eaves by the length of the slope.

In order to find the true length of the hip rafters, refer to the plan of the roof, as shown in fig. 21. At one extremity of the dotted line which represents a hip rafter in plan, draw a line at right angles equal in length to the rise of the roof. Then join the end of this line to the other extremity of the plan line, thus forming a triangle. The hypotenuse of this triangle will equal the true length of the hip rafter. The length of the common rafters can be easily measured from the sectional elevation of the building. For the jack rafters a mean length of the whole will give sufficient accuracy, and for this purpose, half the length of a common rafter can be taken as the mean length of the jack rafters.

General notes. It should be noted that the higher the rate the greater should be the accuracy with which quantities are calculated. Where rates are paid per cubic foot as in woodwork, or per square foot as in doors and windows, the dimensions should be taken to the

nearest half-inch. When dealing with walls, it should be remembered that a few inches added to the height or length have little effect on the total volume, but in the thickness every half-inch affects the result very considerably. Iron work, including bolts and spikes, is usually rated per cwt., and masonry, including concrete, per 100 cubic feet. The unit of measurement for plastering, painting, tarring, oiling, and also for roofing materials is usually per 100 square feet. Rates must always be increased where labour or materials of an exceptional nature are required.

When the abstract of an estimate for a forest building has been completed, it is useful to work out the rate per square foot, or 100 square feet, of area covered by the building. If this is done for several types of buildings the figures obtained will allow a rough estimate to be made of the cost of any building of a certain type by merely ascertaining the area it is to cover.

Schedule of Rates. A local schedule of rates should be maintained for each separate district. It is very important that the schedule be revised continually and brought up-to-date or there is great danger that the highest rates shown will be paid without reference to actual current prices and conditions. The revision of the schedule should be done in consultation with other forest officers and also with other departments if work of a similar nature has been carried out in the district. Prices of materials and the cost of labour are continually changing in a district and depend chiefly upon the local supply and demand. For instance, if any large constructional work such as a new railway is started in a district the cost of labour immediately rises. An extract from a local schedule of rates is given below for reference.

Item No.	Description of Work.	Unit.	Rate.	Remarks.
			Rs.	
1	*Pyinkado* 1″ T. & G. plank flooring	100 sq. ft.	48/-	
2	Galv. C. I. roofing, 24 B.W.G.	100 sq. ft.	40/-	with screws.
3	Bamboo mat-walling with frames	,,	10/8/-	single mat.
4	9″ diam. *Pyinkado* posts	r. ft.	-/12/-	

The above rates have been taken from a schedule used in Upper Burma in 1927 and have been used in the preparation of the Abstract of Cost shown on p. 61. The estimate shown is for a cookhouse for a standard Forest rest-house.

EXAMPLE OF ESTIMATE FORM.

Details of Measurements.

Particulars.	No.	Measurements. Length.	Breadth.	Height.	Deductions.	Contents.	Total of each.
COOK-HOUSE.							
1. Post holes	4	.. ..		..	..	4	4 no.
2. *Pyinkado* posts 9″ diameter ..	4	13 ..		..	..	52	52 r. ft.
3. Woodwork—							
Post plates ..	2	$10\frac{3}{4}=21{\cdot}5$		..	..	..	
Ties	2	$10\frac{3}{4}=21{\cdot}5$		..	..	..	
Rafters	2×2	12 =48·0		..	..	..	
		91·0	5″	2″	..	6·32	
Ventilation rafter	2×2	3 =12		..	..	..	
Purlins	6	15 =90		..	..	..	
		102	4″	2″	..	5·67	
Ventilation purlins	4	15	3″	2″	..	2·50	
Door verticals ..	2	$6\frac{1}{2}=13$		..	..	..	
Window verticals	2×2	$3\frac{1}{2}=14$		..	..	..	
		27	3″	3″	..	1·69	
Cleats to purlins	20	$\frac{1}{2}$	3″	2″	..	0·42	
Total ..	..	.. ..		..	..	..	16·7 c. ft.
4. 24 B.W.G. corrugated iron walls including frames	4	10	8	..	..	320	
Gables	2	10	$4\frac{1}{2}$	..	..	40	
Deduct for—						360	
Doors	1	3	6	..	18	..	
Windows ..	2	3	2	..	12	..	
					30		
Total ..	..	.. ..		..	..	..	330 s. ft.
5. Battened doors and windows as per above deductions	..	.. ..		..	..	..	30 s. ft.
6. Concrete in lime floor	1	10	10	$\frac{1}{2}$	..	41	41 c. ft.
7. Corrugated iron roofing 24 B.W.G. ..	2	15	20	..	..	540	
Corrugated iron roofing ventilator ..	2	15	3	..	..	90	
Total ..	..	.. ..		..	..	..	630 s. ft.
8. Galvanized iron ridging 20 B.W.G. ..	1	15 ..		..	..	15	15 r. ft.

Abstract of Cost.

Item No.	Quantity.	Particulars.	Rate.	Per.	Amount.	Total.
			Rs.		Rs.	Rs.
1	4 no.	Post holes	-/4/-	Each.	1/-	
2	52 r. ft.	9″ diameter *pyinkado* posts	-/12/-	r. ft.	39/-	
3	16·7 r. ft.	Woodwork	3/12/-	cu. ft.	62/-	
4	330 sq. ft.	24 B.W.G. corrugated iron walls including frames	48/-	100 sq. ft.	158/-	
5	30 sq. ft.	Battened doors	1/4/-	sq. ft.	38/-	
6	41 cu. ft.	Concrete in lime	40/-	100 sq. ft.	16/-	
7	630 sq. ft.	24 B.W.G. corrugated iron roofing	40/-	100 sq. ft.	252/-	
8	15 r. ft.	Galvanized iron ridging 20 B.W.G.	1/4/-	r. ft.	19/-	
						585/-

Add Contingencies at 5 per cent. . .	29/-
Total estimated cost . .	Rs. 614/-

IV

FOREST ROAD ALIGNMENT

FOREST roads are made chiefly for the transport of timber, but also in order to provide a convenient means of communication from one part of the forest to another. The great importance of adequate roads is not always fully recognized. The actual value of a forest depends largely upon its accessibility, and Burma hardwoods, such as *pyinkado* and other non-floatable timbers, have at present no market value until they are made accessible by roads; and the price obtained for the standing timber depends entirely on its distance from a railway, and the nature of the road by which the timber can be extracted.

1. CLASSES OF FOREST ROADS

There are four classes of roads which a Forest Ranger is generally called upon to make: main cart-roads, forest cart-roads, bridle-paths, and inspection paths.

Main cart-roads are usually metalled, unless a good natural foundation exists, and are used chiefly for communication and transport between the forest and the rail-head. They are made as straight and direct as possible and must be well drained, as they are generally used throughout the year. When these main roads are also used for the transport of agricultural produce by neighbouring villages they are usually constructed and maintained by the local District Council, or Municipality, but there is often a considerable distance between the end of the District Council roads and the forests, and this distance has to be crossed by Forest Department roads. The width of main roads may vary from 12 feet to 22 feet or more, according to the importance of the road and the amount of traffic. The width of actual metalling is usually about 12 feet, the extra width consisting of earth 'backing'.

Forest cart-roads are mainly intended for the extraction of heavy timber, and act as feeder roads to the main roads. These are the roads with which a Ranger is most concerned and will be dealt with in detail later. They are usually earth-roads, although in some cases the surface may be improved by the addition of laterite, sand, or gravel. The standard width for forest cart-roads is 12 feet.

Bridle-paths. These are sometimes called 'elephant paths'. They are designed to form a quick and direct route from place to

place, and are chiefly used by pack animals, particularly baggage elephants. A steeper gradient is permissible for bridle-paths than for cart-roads, and therefore in hilly country they are much shorter. Bridle-paths are often constructed to form communications where the expense of a cart-road would not be justified. They are also very useful as an alternative route during the rains when it is desirable to avoid damaging the surface of the cart-roads by baggage elephants. The standard width of a bridle-path is 6 feet; on hillside paths this means the actual width cut out of the hillside and does not include the loose earth thrown out of the cutting. All high banks and overhanging trees which are likely to touch the pack of a loaded elephant must be cut away.

Inspection paths. These are merely narrow tracks, about 2 feet wide, cleared of undergrowth on each side just sufficiently to enable a man to pass easily. They are intended for the inspection of plantations or other forest work, and also to enable subordinates to patrol their beats. In the case of plantations they should be demarcated in the first year of formation, preferably just after burning, while the contour of the ground can easily be seen. Inspection paths must be cheap. They should usually follow main ridges, and in hilly country should connect places from which an extensive view can be obtained. The paths should be made accessible for a pony where possible, but deep cuttings or expensive embankments must be avoided, extra length being unimportant. Each path should form part of a general plan, so that a network of paths covering all important places will be made eventually. All existing roads and paths should be clearly marked on a map before any new construction is commenced.

Temporary roads. These roads are occasionally constructed by the Forest Department to assist contractors to extract timber from near the felling site to the existing cart-roads, but they are more often made by the contractor who is working the area. If these roads are properly aligned from the beginning they can, if required, be improved later into more permanent roads.

All possible assistance should be given to the contractor in laying out his roads. As they are purely extraction roads they will usually follow the valleys and low ground. They will be required for a period of three to five years only, and the construction must be cheap, so the alignment is taken round the sides of hills and other obstacles to avoid expensive cuttings or embankments. The main point is to avoid steep uphill gradients in the direction that the load will be carried, which is usually described as 'against the load'.

2. GRADIENT

Measurement of gradient. The gradient or longitudinal slope of a road is of great importance. It is often expressed by the difference in level or height which occurs in a certain horizontal length; for example, 1 in 20 means a rise or fall of one foot in 20 feet of length, but in certain instruments, such as the Abney level, the slope is expressed in degrees of elevation above a horizontal plane.

A slope of one degree equals a rise of one foot in a horizontal distance of 57·3 feet, a slope of 2 degrees equals a rise of one foot in 28·6 feet, and 3 degrees equals one in 19·1 and so on. Where it is required to change the terms of expression from one form to the other, it is usual to divide into 58; for grades up to 6 degrees this is sufficiently accurate for all practical purposes. For instance, to find the angle in degrees equivalent to 1 in 20: 58 divided by 20 is equal to 2·9, or 2 degrees 54 minutes; and to find the horizontal equivalent of an angle of 3 degrees, 58 divided by 3, gives approximately 19. The actual equivalents of the gradients most commonly used in road work, correct to the nearest 10 minutes, are as follows: 1 in 10 $= 5^\circ\ 40'$; 1 in 15 $= 3^\circ\ 50'$; and 1 in 20 $= 2^\circ\ 50'$, and these can easily be remembered. In most European countries, and in America, the gradient is usually expressed as a percentage; a 5 per cent. grade meaning a rise of 5 units in a horizontal distance of 100 units, which is the same as 1 in 20.

Importance of gradient. An engine which can haul a load of 3 tons along a level surface on an earth-road can haul, on the same gear, only two tons up a gradient of 1 in 20, and only one ton up a gradient of 1 in 10. On the smooth hard surface of a metalled road the effect of the gradient is even greater, as there is not so much surface friction, and only half the load can be hauled on a gradient of 1 in 20 compared with a load on the same hard surface on level ground.

Cartmen adapt their loads to suit the gradient and will put on light loads if the road is badly graded. It must be remembered that even one steep gradient on a road will generally mean reducing the loads which will be carried along the whole road.

Maximum gradient. A maximum or 'ruling' gradient has been laid down definitely for both cart-roads and bridle-paths, and this must be strictly followed when making alignments. For forest cart-roads the maximum gradient is 1 in 20, but for short distances with the load the gradient may be increased to 1 in 15. For bridle-paths the maximum gradient is 1 in 10, except for short distances in difficult country, and for short natural slopes when following the tops of

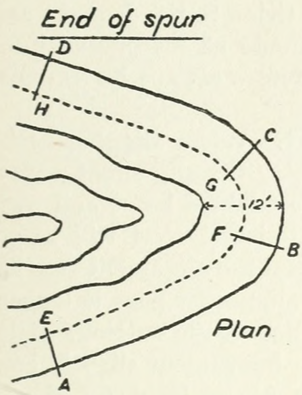


FIG. 33

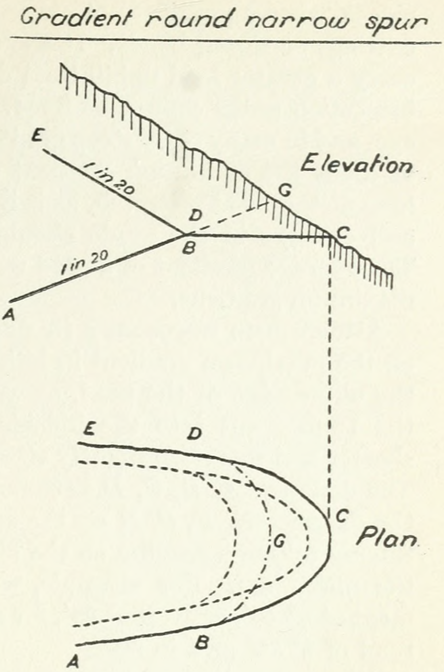


FIG. 34

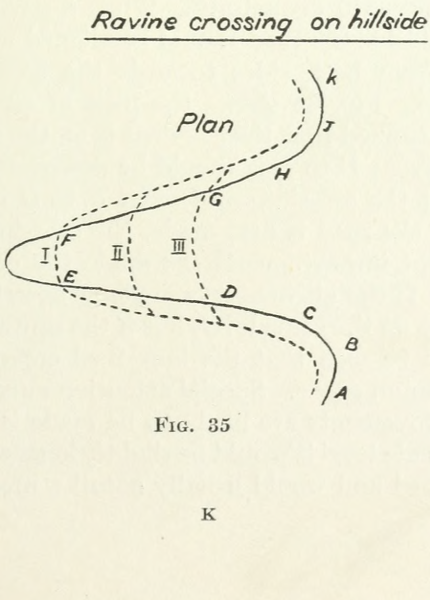


FIG. 35

ridges, when a gradient not exceeding 1 in 7 may be used to save deep cuttings or zigzag bends. It should be noted that pack animals can carry a greater load uphill than downhill. A maximum gradient for inspection paths cannot be fixed. These paths should be aligned by eye, and in many cases steep gradients are unavoidable. On all classes of roads the maximum gradient should not be maintained for very long distances at a stretch, as it is very tiring to the draught animals, and changes in the grade should be made at reasonable intervals. The average gradient of a road will therefore always be less than the maximum gradient.

Allowances necessary in gradient. When aligning cart-roads on the maximum gradient in hilly country the alignment pegs follow the outer edge of the road, as will be explained later, and owing to the 12-foot cut into the hillside the finished road will always be shorter and therefore slightly steeper than the alignment (see fig. 33). The distance *A*, *B*, *C*, *D* between the alignment pegs is longer than the distance *E*, *F*, *G*, *H* on the centre line of the cutting. Allow for this by taking a reading on the aligning instrument slightly less than the maximum. For example, with an Abney level, set the instrument at 2° 40′, or even 2° 30′, for a maximum gradient on the finished road of 2° 52′ or 1 in 20.

Where the alignment passes round long and narrow spurs on hillsides it should either be taken level, as at *B*, *C*, *D*, in fig. 34, or slightly upwards to the end of the spur at *G* and downwards on the other side to *D*, as this allows for the spur to be cut off later if necessary without exceeding the maximum gradient.

Gradient at stream crossings. When a stream or deep ravine is crossed on a hillside the road should be aligned with a slight downward gradient from both sides towards the crossing place of the stream or ravine. Fig. 35 shows the plan of an alignment at the crossing. It is assumed that the gradient is on the maximum upward from *A* to *D*. From *D* to *E* it should be downward; from *E* to *F* it must be level at the crossing; and from *F* to *G* it should again be upward. When the road is first made, the crossing *I* will be taken, but as subsequent improvements are made the crossing may be at *II* or even *III*. If the alignment is made as described above, *G* and *D* will be roughly on the same level, but if the upward grade had been continued it can be seen that the improved crossing would greatly exceed the maximum grade. Special attention must be paid to places where such improvements are likely to be made later. If the whole alignment was made level it would be slightly longer than the 'reversed gradient' described and would usually entail a more acute bend.

The above does not apply to crossings of very small ravines or hollows at which it is not intended to construct a bridge, culvert, or other form of cross-drain. In these places the alignment should be taken round level, or with a slight continuous gradient, to prevent drainage from the two sides washing out the crossing.

Where there is a considerable length of hillside road without a stream crossing or other break in the alignment, a short dip in the grade should be made at intervals to provide for drainage. These dips will form cross-drains and will help to prevent water running down and eroding the road surface. They should always be made at the ends of spurs or in places where there is no serious danger from side erosion.

Evenness of grade. On all roads there are certain places such as selected stream crossings, or the lowest saddles on ridges, through which the road must pass. Such places are called 'obligatory points' and the gradient should be as even as possible between any two of these points. The road should never be aligned to follow the top of a ridge to the extreme end and then suddenly descend by 'zigzags' into the valley below, but should begin descending some distance from the end of the ridge. Where one obligatory point is higher than the next the alignment should show a steady fall, and a rising gradient in any portion between the two points is generally a mistake. There are, however, some situations where a rising gradient between the two points will be found necessary to avoid obstacles.

3. INSTRUMENTS USED IN ALIGNMENT

The maximum gradient for the various classes of road having been fixed, it is necessary to use some instrument which will enable us to measure this gradient when making an alignment. Many different kinds of levelling instruments and clinometers are used for this purpose. Some forest officers prefer one kind and some another, depending chiefly on the instrument to which they are most accustomed, and Rangers will use the instruments which are available in their particular forest divisions. The three instruments most commonly used for the alignment of forest roads are the Abney level, the De Lisle clinometer, and the Ghat tracer. The Watkins clinometer is occasionally used but is not very suitable for forest work, as it cannot be fixed at a given slope, and in dense forest the figures are not easy to read.

The Abney level. This instrument consists of a square metal tube, 4 to 5 inches long, open at one end, and with a sight aperture in a sliding telescopic tube at the other end. At the top is a small spirit-level to which is attached an index arm that can be revolved

round a horizontal axis by a milled wheel. The index arm slides on a semicircular arc graduated to whole degrees, and a vernier on the arm enables readings accurate to ten minutes to be made. A slot in the upper side of the main tube allows the bubble of the spirit-level, when it is in the centre of its run, to be reflected in a mirror directly to the observer's eye looking through the sight aperture. The bubble, when level, appears to be bisected by the horizontal wire which is stretched across the open end of the tube.

To use the instrument it should be supported on the top of a bamboo staff, which is cut at a convenient size for the observer's height. A sight-vane is made of another staff, with a horizontal crosspiece attached so that it is at exactly the same height as the horizontal wire of the Abney level when the latter is placed on its supporting staff. The sight-vane used by surveyors is usually fitted with a cross-piece or vane, which slides up and down to suit the observer's height, and which consists of a painted board, 12 inches by 9 inches, fitted with a clamp; but for forest work it is usual to improvise a sight-vane from bamboos. The crosspiece should be as large as possible to enable it to be easily picked out when sighting through the Abney level in dense jungle.

The Abney level is sometimes used simply held in the hand without the help of a supporting staff, but this method is not nearly so accurate, especially in rough hilly country. A bamboo staff is easily carried, and the bubble in the level is steadied down much more quickly if it is given a rigid support.

Where an Abney level is required for finding an unknown gradient, first set up a sight-vane as far as possible along the gradient, and set the Abney level on its staff at any convenient point. Then push the telescopic tube in or out till the sight-vane and the horizontal wire in the end of the level are both clearly defined, and incline the instrument up or down till the wire and sight-vane appear to touch. Then turn the milled head of the level until the reflection of the bubble is seen at the mirror's edge bisected by the horizontal wire. It will be found necessary to turn the milled head towards you if looking down hill but away from you if looking uphill. Then remove the level from the staff, and the gradient in degrees and minutes can be read from the index arm on the graduated arc.

When using an Abney level for laying out a section of road at a fixed slope, move the index arm to the gradient desired, and then do not touch the milled head or level tube again. Hold the level on its supporting staff, pointed in the required direction, and incline it slightly up or down till you see the bubble reflected in the mirror and bisected by the horizontal wire. Now direct the man carrying the sight-vane

to move up and down the slope until the crosspiece on the sight-vane appears to touch the wire. The sight-vane is then on the required gradient. To check if the level is in proper adjustment first check your sight-vane and supporting staff to see if they are exactly the same height, then drive in two stout pegs about 20 yards apart and on fairly level ground. Set the Abney level to zero and place the supporting staff on one peg and the sight-vane on the other. Adjust the pegs until the wire cuts the bubble, and also the crosspiece of the sight-vane. Reverse the position of the sight-vane and Abney level and read from the opposite peg. If the wire, bubble, and sight-vane do not all three now agree the instrument is not in adjustment. Note the amount of error. The necessary adjustment should then be made by slightly moving one of the two screws on the top of the level tube until the instrument reads *half* of the original error. Then drive in the pegs until the sight-vane agrees with the horizontal wire. The pegs should now be dead level. Check from the other end and, if necessary, repeat the process until the two readings agree. Great care should be taken in adjusting the small screws in the level tube, as these have very fine threads and are easily damaged and then become loose. *All clinometers and levelling instruments should be checked each morning before work is started.* Many instances are known where a complete alignment has had to be done again as a result of not checking the instruments used.

An Abney level is a very handy, portable, and accurate instrument, but it is rather fragile and apt to be damaged by a knock or fall. Slowness in working is also a disadvantage of the level as it takes time to get the bubble and object aligned and the bubble steady. The index arm is also likely to get slightly moved after being set at the required angle, and when moving to a new position on the ground it is always advisable to look at the reading on the arc and see that the arm has not moved. If the milled head has worn loose this movement is frequently happening and wastes time, while if it is too stiff it is difficult to turn steadily and get the bubble into line. In most of the new models a clamping screw is fitted to hold the index arm firmly when using the level for a fixed gradient. Owing to its handiness the Abney level is the best instrument for laying out roads where accuracy is required, and the improved models, which allow of more rapid working, are now becoming very popular for forest road work in many parts of the world.

The De Lisle clinometer consists of a diamond-shaped frame with a mirror fitting the left half (see fig. 36). Above the mirror is a ring from which it hangs freely, and below is a solid arc graduated in

gradients from 1 in 5, to 1 in 50, against which moves an index arm. Along the index arm slides a plumbob. In some instruments there is a milled screw in the axis of the index arm which clamps the arm to any desired gradient. The arc, with its arm, turns round on a vertical axis so that the mirror and the arc can be placed in the same plane for carrying the instrument in its case. When in use the mirror is turned at right angles to the plane of the arc. For reading gradients *uphill* the mirror is turned *towards* the axis of the arm as shown in fig. 36, and for *downhill* gradients it is turned to face *away* from the arm axis.

When using the clinometer to read level the plumbob is pulled out to the extreme end of the index arm, up to the line marked *LEVEL*, and the index arm is moved to the graduated mark 50. When reading gradients it must be remembered to slide back the plumbob to the upper line on the index arm, marked '1 *IN.*', and clamp it, if it has a clamping screw. A sight-vane is made and used in the same way as for the Abney level. In dense jungle a white handkerchief fastened to the vane assists in finding it quickly.

For forest work it is advisable to attach the clinometer ring to a short crosspiece, fixed to a supporting staff so that the mirror is at the same height as the eye of the observer, as this gives more accurate results than if the clinometer is simply held in the hand.

If a supporting staff is used it must be held so that the instrument swings freely from the ring and at a height to enable you to see conveniently in the required direction through the vacant half of the diamond frame containing the mirror. Move your head up and down till you see your sighting eye reflected in the mirror, and twist the staff round slightly to right and left till you see the corner of your eye at the centre of the edge of the mirror. Then signal to the man carrying the sight-vane to move it up or down until the crosspiece appears in line with the reflection of the corner of your eye in the mirror. This will give the required gradient.

To test the De Lisle clinometer for adjustment set it at 'Level' and take level readings from two pegs alternately in the same manner as described above for testing the Abney level. If not in adjustment it can be corrected by turning very slightly the large screws placed just below the mirror frame; these tilt the mirror slightly with regard to the whole instrument.

The De Lisle clinometer is quicker in use but less accurate than the Abney level. It is specially useful in roadwork for making the preliminary trial lines where great accuracy is unnecessary, the permanent grade pegs being placed later with an Abney level.

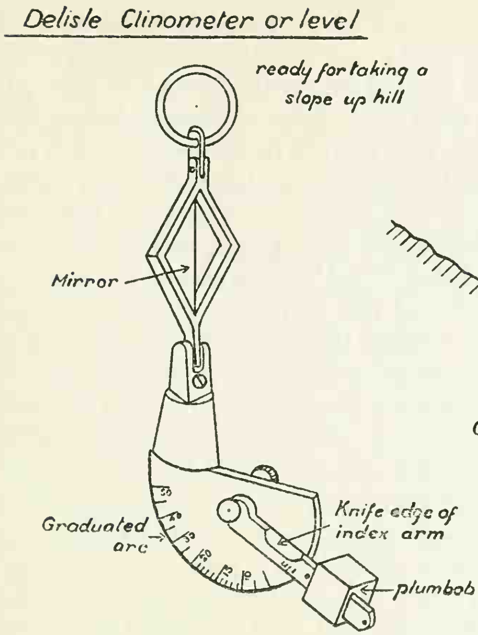


FIG. 36

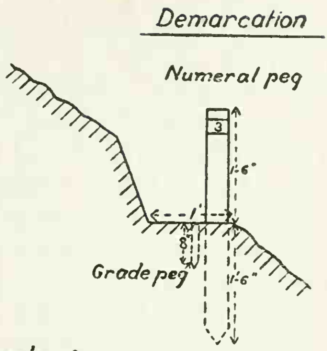


FIG. 37

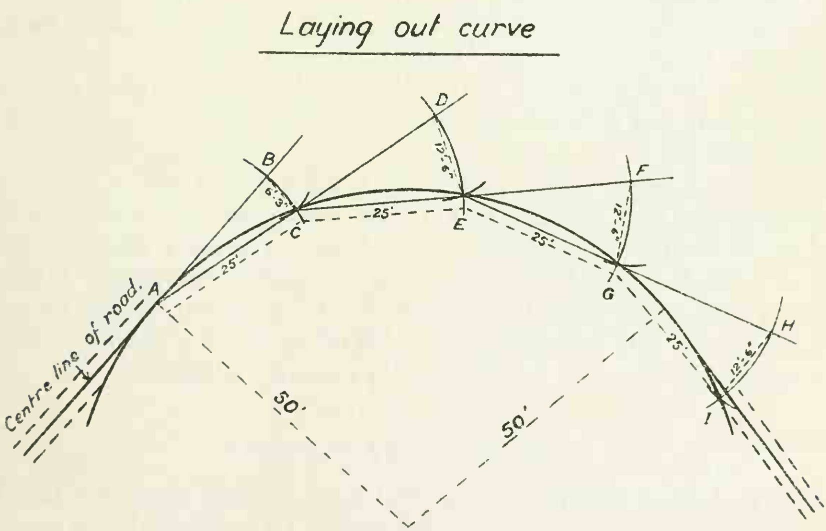


FIG. 38

The Ghat tracer consists of a triangular metal frame, each side measuring 9 inches. The apex of the frame is fitted with an axis or pivot about which the whole instrument can swing in the plane of the triangle. This axis is fixed into a straight staff, about 1½ inches square, at about 6 feet from the bottom, or at such height as suits the observer's eye. The lower part of the instrument consists of a hollow brass tube, 1 inch diameter, and has a plumbob which slides along it and can be clamped at any position. The tube has graduations marked along it showing grades from 1 in 6, to 1 in 120, the mark at the centre of the tube being 'level'. One end of the tube has a pin-hole in it, and the other end has two wires crossing at right angles, the line of sight being through the tube. The method of using the tracer is the same as described for the two previous instruments. When required to find the slope to a fixed object, take the frame out of its box and attach it to the staff by the pivot. Then rest the staff vertically on the ground and slide the plumbob along the lower bar, forwards if the object is downhill and back towards you if uphill, until the sights when looked through are aligned upon the object. Then read the gradient on the outside of the sighting tube.

To lay out a road or a line at a fixed gradient, clamp the plumbob at the gradient mark required, and send a man to hold a sight-vane, of the same height as the height of the tracer sights, on such a level that the sight-vane appears in line with the sights. This spot will be at the desired gradient from the site of the instrument. To find if the tracer is in adjustment, test it in the same way as for the De Lisle clinometer. If not correct, there are no means provided in the tracers ordinarily supplied for putting them in adjustment, and it is usually necessary to return them to the makers for repair.

The Ghat tracer is much bigger and heavier than any of the other clinometers. It is portable and is very strong, and not easily put out of order, but in dense jungle it is cumbersome to carry about, and an Abney level or De Lisle clinometer is usually preferred. A Ghat tracer must be supported on a staff or rod for use and cannot be used in the hand. It is very accurate, and is often used for alignment work in open hilly country, for which it is specially adapted.

4. METHOD OF ALIGNMENT

It is of great importance that the best possible alignment should be obtained before a road is constructed. An earth-road gets gradually better from year to year through continual maintenance and

improvement, and is often converted ultimately into a main metalled road. If the best possible alignment has been made for the original road all the work done on the road-surface is cumulative, but if the road has to be re-aligned all the previous work is thrown away. The cost of carrying out an alignment is comparatively small, as very little labour is required, and any extra time spent on making alternative trial lines will be more than repaid by saving unnecessary expense both in construction and subsequent maintenance.

Preliminary reconnaissance of the ground. If a map is obtainable the first step to be taken is to study the map carefully and note the general physical features, especially the direction of the main ridges and positions of streams. Then, before using any instruments, walk over the whole length of the proposed route, several times, map in hand, paying special attention to broken ground, stream crossings, and possible alternative routes. In hilly forests any existing paths, especially wild elephant tracks, give useful indications of the best route, as they usually cross the lowest saddles of ridges; but village paths often ascend and descend needlessly and make long detours to avoid obstacles which may easily be removed when making a road.

Many books on hill-road construction recommend that the theoretical average gradient between two obligatory points should first be worked out from the map, for use as a guide in fixing the gradient. It can easily be found by dividing the difference in height, shown by the contours on the map, by the length of the distance between them. This is useful in mountainous country where there are long even slopes of several thousand feet in height, but in the broken hilly country in which most Burma forest roads are constructed the theoretical average gradient has been found to be of little value in actual practice. No useful estimate can be made of the actual length of the road between two points in broken country, as the map gives only horizontal distances, and also does not show the obstacles, and the length can only be found by running trial lines actually on the ground. Aneroid barometers are very useful for showing the comparative heights of the various obligatory points, particularly of saddles on ridges, but these instruments are expensive and are rarely available for forest work.

When walking along a ridge note which side is the steeper, and look out for precipices or other obstacles; and in rocky country note the dip of the layers or 'strata' of rock, so that steep or unstable slopes may be avoided. Where possible get a local man who is familiar with the country to accompany you, as he will often know of existing paths and roads which are not marked on the map. Portions of old existing

roads can often be included in a new road and save considerable expense in clearing and new construction. Old roads may also act as feeder roads to the new road. Two parallel roads at short distances apart are to be avoided, as one road can usually be made to serve the purposes of both.

Obligatory points. After the country has been thoroughly examined, fix any obligatory points. As already mentioned above, these are points through which the road must pass. They may be the lowest saddles on ridges, best crossings of streams, or special objects which the road is required to reach, such as plantations or villages. It is usually impossible to fix many obligatory points until the gradients have been tried as it cannot be foreseen which saddles and stream crossings will be reached, but there are often one or two main points which are unavoidable and which can be fixed at once to indicate the route to be followed. When these obligatory points have been fixed the proposed alignment may be lightly pencilled on the map.

Deviations. It should be noted that a small deviation from the direct straight line between two points does not add very considerably to the length of a road. A deviation to the right or left of a straight road joining A and B, equal to one-tenth of the whole distance between A and B, will increase the length of the road by one-fiftieth only, provided that the deviation is not near the ends of the road.

If a road is taken straight over the top of a hill it may not always be the shortest. This can easily be seen by taking a hat and measuring the distance from front to back, first straight over the top and then round one of the sides. It will generally be found that the distance round the side is shorter. Deviations to avoid hills and other obstacles can therefore often be made without adding much to the length or cost of a road. Such deviations may also be made in metalled roads to include a stone quarry, and in some localities deviations are necessary in a road to include a spring or other watering point for draught animals. A considerable detour is generally justifiable in order to avoid an unnecessary ascent, and it is a common rule in road alignment to make a detour when the increase in length is not more than fifteen times the height saved. For example, a detour which will be 1,500 feet longer than the direct route is justifiable to avoid a hill 100 feet in height.

Alignment in the hills. When carrying out an alignment in the hills the special object for which the road is required must first be carefully considered. A road intended for timber extraction should follow the valleys rather than the ridges, and should be as near as

possible to the lower boundary of the working area, so that timber can be dragged downwards to the road. On the other hand, bridle-paths and other roads which are to be used chiefly for communication should follow the tops of ridges wherever possible, as they will generally be used throughout the year and need good drainage; and a road along a ridge or watershed is always the cheapest as stream crossings are avoided.

After the obligatory points have been fixed and a rough approximation of the route marked on the map, the more difficult and broken parts of the ground should be tackled first, as already indicated. In mountainous country it is usually considered advisable to start at the highest obligatory points and work downwards to the obligatory points in both directions, as the upper slopes are steeper and offer less choice of ground; but in very broken country and in dense forests, it is easier to see obstacles, such as a steep precipice, from below, and the alignment can then be carried out more easily uphill. The best general rule to follow is: *First get out of difficult ground on the maximum gradient, and then join up the sections on easier ground with gradients as even as obstacles will permit.*

A prismatic compass survey is generally of little or no value in hilly country, but in very dense jungle, and where the natural features of the country are not prominent and cannot easily be defined from the map, a straight line along the magnetic bearing from an obligatory point to another known point may be surveyed and roughly demarcated by blazed trees. This may form a useful guide in finding your exact position on the map at intermediate points, and may assist in keeping the alignment as straight as possible, as it will be known whether to bear to the right or left to get on to the shortest route.

The alignment must be made level at the sites of all bridges and culverts, and for a distance of about 50 feet on each side of them. This is often neglected and causes trouble when the bridges or culverts are constructed, which is usually some time after the remainder of the road has been completed. A level or almost level alignment should also be made at all sharp bends to allow for subsequent straightening, as already mentioned. On hillside roads wide halting places should be prepared and levelled off, especially near watering points, so that carts do not halt on the road and cause other traffic to cut down the banks. Long stretches of dead level alignment should be avoided as level roads hold the surface water and are difficult to drain. A slope of 1 in 120 is sufficient to ensure drainage.

Alignment in level country. In level country a road may some-

times be aligned for a considerable distance in a straight line, and where there are no obstacles the compass bearings can be obtained from a map and the centre line of the road then demarcated with the aid of a prismatic compass and ranging rods, as for ordinary survey lines. When working with ranging rods in dense jungle it is necessary to check the bearing with the prismatic compass about every hundred yards, as a small error at the beginning of a line will increase directly in proportion to the length of the line, until it is again corrected by the compass. The chief considerations in aligning a road in level country are to avoid unnecessary crossing of streams and natural drainage channels, to keep on high ground wherever possible, and particularly to avoid swamps and low-lying places. In very dense jungle a plane-table survey of a finished alignment is often advisable, as it shows up any unnecessary bends in the line, but this is not necessary in open hilly country.

Trial lines. Several trial lines should be roughly aligned, and after careful comparison the best one chosen. This especially applies to hilly country. The selection will depend chiefly upon the relative cost of the various lines, but their length must also be considered. The cost of construction has always to be balanced against the saving of cost of transport, and if the amount of traffic is sufficient it may justify the additional cost involved in making the extra cuttings needed for a less steep or shorter road. The best line will be a compromise between length, cost, and gradient.

The actual value of a road is very difficult to estimate, especially if the road is also to be used for communication, and the economics of road construction is too large a subject to be dealt with here. It should be noted, however, that in calculating the difference in cost between several trial lines the cost of subsequent maintenance, as well as first construction, must be taken into consideration. For example, wooden bridges require replacement every fifteen or twenty years and are therefore very expensive to maintain, and the upkeep and repairs for embankments and deep cuttings also cost much more than for ordinary sections of road.

5. SETTING OUT ROAD CURVES

In hilly country the roads naturally follow the contours of the hills, and acute bends are often only avoidable by making very expensive cuttings. For bridle-paths these bends are not important, but for cart-roads the width of the road at all acute bends must be increased to enable loaded carts to pass easily. The amount of increase in the

width will depend upon both the degree and the radius of the curve, but a width of 18 to 24 feet will usually be sufficient. When constructing a forest cart-road at a re-entrant bend, as when crossing a small ravine on a hillside, it is necessary to make certain that the largest log which is likely to be extracted, say 30 feet long, will be able to pass round the bend easily. This can be tested by simply carrying a piece of bamboo 30 feet in length down the centre of the road, keeping it horizontal and about 3 feet off the ground. If it touches the banks, more cutting is obviously necessary at that point. This rough test will give the whole clearance necessary for ordinary two-wheeled timber-carts, as a long log projects beyond the yoke in front and no extra allowance is therefore required for the draught animals or cart.

Curves on roads in level country, especially where the road is on an embankment, should be set out as evenly and regularly as possible. Badly set out and awkward bends are frequently seen on forest roads, and if any of these roads are used in the future for motor traffic they will need expensive reconstruction.

On important main roads the curves are correctly set out by engineers, with the assistance of a theodolite, but for forest work we require simple, if less accurate, methods which can be carried out without instruments. The minimum radius for curves on forest cart-roads is generally considered to be 50 feet; exception being made in hilly country, where the cuttings involved would be too expensive, as already mentioned. In practice very little attention is paid to the actual radius and we are satisfied if a curve is set out fairly regularly. A trial and error method is the simplest and most frequently used. Pegs are put in at the points where previous experience indicates that the curve should begin and end, and then a few intermediate pegs are put in by eye along the inner side of the bend. A string is stretched along the line of pegs, which are adjusted by trial and error until a fairly even curve is obtained, and this is all that is usually attempted by forest road contractors.

Setting out a curve by offsets. A better method, which should be used in the alignment of embanked roads and for all important roads in level country, is known as the 'offset' method; and by this means a curve of any particular radius can be quickly aligned without the use of instruments. We will take as an example the setting out of a curve of 50 feet radius, which, as mentioned above, is the minimum radius prescribed for forest roads. All that is required is a 25-foot tape and a piece of string or cord 12½ feet long. For convenience in working, both the string and the tape should have pointed pegs attached to both ends.

First mark off two points *A* and *B*, with pegs 25 feet apart, along the centre line of the road, starting at the point *A* at which it is desired to begin the curve (see fig. 38). Keeping one end of the tape at *A*, swing the other end inwards from *B* in the direction of the bend, keeping the tape tight, and with the attached peg mark out a short arc on the ground about 7 or 8 feet long. Then take the piece of string and, with *B* as centre and *half* the length of the string as radius, describe another arc, cutting the first arc at *C*. Drive in a peg at *C* which will be on the required curve. Take the 25-foot tape again and mark off *CD* in line with and in prolongation of *AC*, and with *C* as centre describe another small arc as before; then with *the whole length* of the 12-foot 6-inch string as radius and *D* as centre, cut this arc at *E*. Mark out *EF* in prolongation of *CE* as before, and continue in this way until the new direction of the road is reached. The chief thing to remember when using this method is that for the first offset *BC* only half the length of the string is used, and for the remainder of the offsets the whole length of 12 feet 6 inches is used.

Where the curve is required for joining two existing roads the chief difficulty is in fixing the point *A* at which to start the curve, and the only simple method of finding this point is by trial and error. If the end of the curve does not meet the second road at the first attempt, start again from a different point *A* along the centre line of the first road; or in some cases it will be found better to start from the same point, and make a wider curve by using a shorter length of string for the offsets. Twelve feet six inches is the longest offset that can be used with a 25-foot tape without reducing the minimum radius of 50 feet.

Zigzags. A series of hair-pin bends, or 'zigzags' as they are called, should be avoided especially on cart-roads. Even on bridle-paths it is better to have a few short steep grades than a series of carefully aligned zigzag bends which often would not be used by the pack animals. Zigzags are bad for traffic, and are expensive to construct and to maintain. They can often be avoided at the ends of long ridges by starting the descent at a point farther back along the ridge; and in the case of an isolated hill by taking the road farther round the hill instead of ascending on one side. Where zigzags are unavoidable the curve should be laid out as shown in fig. 39, in order to allow carts loaded with logs to pass round easily. The portion of the road at the curve must be level, and this will usually mean cutting deeply into the hillside for the upper part of the turn, and also embanking and revetting the outer side of the road.

Where possible, select sites for zigzag bends which are already

ALIGNMENT OF ZIGZAG ROAD

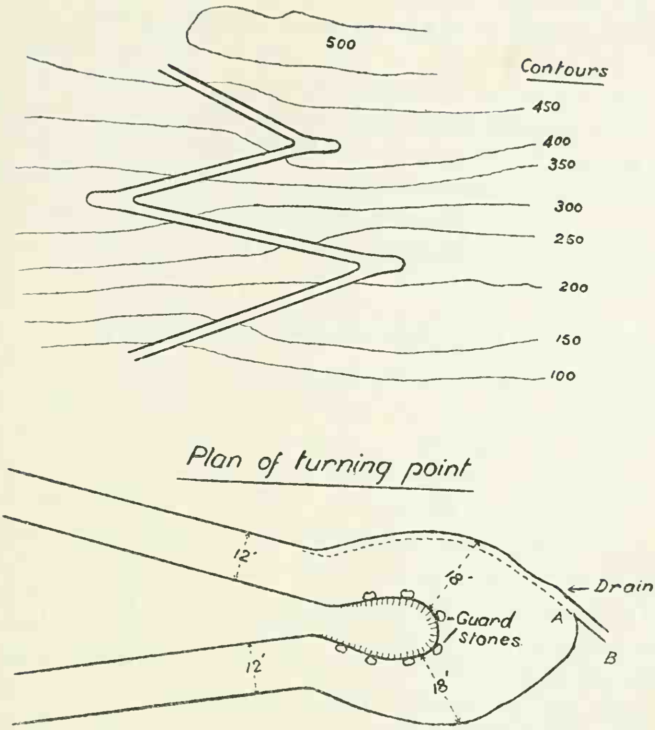


FIG. 39

IRISH BRIDGE

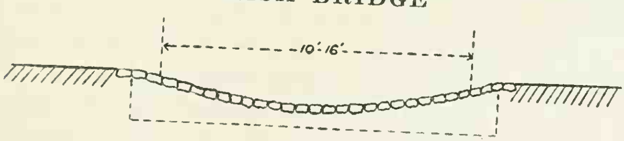


FIG. 40

fairly level or less steep than other parts of the hillside, as shown in the elevation of a road in fig. 39. Remember that the distance between the contours shows the relative steepness of the hill. The drain *AB* in the figure must be led off as shown to avoid washing out the built-up portion of the level road, and all drainage water should be diverted from the bend. A stone wall of rubble, or a line of guard stones, as shown in fig. 39, should be erected round the inner side of the curve to prevent carts from cutting down the corner. Where stone is not available use timber in the form of stout round posts about 3 feet high. Carts when empty or carrying a light load tend to take the shortest possible route regardless of grade, and this makes it both difficult and expensive to keep a zigzag bend in proper repair.

6. DEMARCATION OF ALIGNMENT

A road alignment is usually made a year or even more before the estimate is approved and construction started. It is therefore necessary to mark out the line in such a way that it will not be easily destroyed and lost. For trial lines, and for the preliminary alignment, bamboo pegs to mark the line are sufficient, but as soon as the line has been definitely fixed these must be replaced by permanent pegs. On hillside roads the pegs represent the outer edge of the road, and on level country they follow the centre line of the proposed road. Two kinds of permanent pegs are used, called 'numeral' and 'grade' pegs.

Numeral pegs. These pegs should be of durable heartwood, 3 feet long, and preferably split from an old fallen tree of teak or *pyinkado*. They should be pointed and driven into the ground at least one foot deep with a heavy wooden mallet, and not with the back of an axe as this splits the wood. Pegs should be put in at each angle or change in the line, on both banks at bridge sites and at all crossing-places of streams, and not more than 100 feet apart in any part of the line. Each peg must be clearly visible from the next. In open level country the pegs may be placed at distances apart of 50 or 100 feet, to assist subsequent calculations.

A serial number should be clearly marked with a numbering cog on each peg before it is put into the ground, and the gradient to the next peg should be written below the number.

Grade pegs. Alongside each numbered peg a small 'grade' peg is driven into the ground with its top flush with the surface. Grade pegs should be from 6 inches to 9 inches long, according to the hardness of the ground. These pegs show the exact level of the proposed road, and are the points upon which the instrument staff and the

sight-vane are supported when marking the finished gradients (see fig. 37 and the photograph on plate V).

At two-sided cuttings, where the grade pegs cannot be placed at the proposed level without excavation, large pegs following the line of the road should be erected, on which the depth of the required cutting must be clearly marked.

One-foot trace. As soon as all permanent pegs have been placed in position a one-foot trace should be cut at once along the whole length of the road. This trace is to be made at the exact level of the proposed road, and should bc constructed as cheaply as possible. When the trace encounters a tree, bamboo clump, or other obstacle which would be expensive to clear, it should stop at the obstacle and commence again from the other side. If taken above or below the obstacle it is misleading, as it is then not at the corrcct level. The trace can be most easily kept at the required gradient between any two pegs in broken ground by 'boning staves', the use of which is explained in detail on page 96.

V

THE PREPARATION OF A ROAD ESTIMATE

FOR general convenience and to simplify subsequent office work all estimates for road work should be prepared on a standard form. A specimen copy of the standard form used in the Burma Forest Department is given at the end of this chapter for reference. This form is for a simple earth-road, and if any form of surfacing or metalling is required it should be prepared on a separate statement.

1. LENGTH OF ALIGNMENT

In the first column of the form is recorded the serial numbers of the alignment pegs. In the second column, the distance from peg to peg is shown on the line between the two pegs; and the running total, from the starting-point or from the end of the last mile, on the line opposite to the peg numbers. This running total is very useful both for general reference and when allotting tasks during construction.

The distance from peg to peg must always be recorded in feet, and finally totalled up at the end of each mile (5,280 feet), but the serial numbers of the pegs should be continuous throughout the whole length of the alignment. When the length of the alignment is being measured a special post should be placed at the end of each mile and clearly marked with the mileage from the starting-point.

2. MEASUREMENT OR COMPUTATION OF EARTHWORK

Compared with timber and other materials, earthwork is cheap, and very detailed accuracy in measurement is therefore unnecessary. The methods explained below give results which are sufficiently accurate for forest roads. Lengths may be measured to the nearest foot, and breadths and depths to the nearest half-foot.

Measurement of hillside cuttings with a slope template. On hillside cuttings the first requirement is the cross-section of the estimated excavation at each alignment peg. This may be estimated in various ways. For main roads over 12 feet wide it is usual to measure the inclination of the slope with a clinometer and then obtain the cross-sectional area from earthwork tables; but for ordinary forest roads a 'slope template' is a much quicker and easier method of measurement.

A slope template can easily be made from local materials on the site (see plate V, and also fig. 41). It consists of a stout vertical bamboo staff, 8 to 10 feet long, graduated in feet and half feet, and

V. (*a*) Using boning staves in placing intermediate pegs on road alignment.
(*b*) Estimating earthwork for hillside road with slope-template.

provided at the base with a hinged or knuckle joint, which can be made of a strip of leather or from a piece of bamboo or creeper. Attached to this staff by the joint is a long arm, formed of a light piece of bamboo about a foot longer than the main staff. Near to the top of this bamboo arm is attached a wire, or strong piece of string. This wire passes through a hole in the main staff and ends in a ring or loop made to pass over one of the small screws or pegs which are fixed in the staff at such heights that the arm may be set at slopes of 1 in 1, 2 in 1, 3 in 1, 4 in 1, or any other slope required. Another straight bamboo rod is also required, and for cart-roads this rod should be 16 feet long and marked off at 12 feet from one end. For the measurement of elephant paths it should be 10 feet long, marked off at 6 feet.

For measuring the cross-section of a hillside road the hinged arm is first set at the slope to which it is proposed to cut the back slope of the road. This will depend chiefly on the nature of the soil, as will be seen later. One man holds the template in position on a grade peg so that the main staff is vertical and the hinged arm pointing towards the hillside. A second man, standing on the slope above the template, takes the other bamboo rod, placing one hand at the 12-foot mark, (or for an elephant path the 6-foot mark). He first holds the bamboo high and horizontal, with his hand against the movable arm, and then lowers the rod, while keeping it horizontal, until the end touches the ground slope, as shown in fig. 41. The height is then read from the vertical rod, to the nearest 6 inches. This height, multiplied by 6 in the case of a 12-foot cart-road, and by 3 in the case of a 6-foot elephant-path, will give the cross-sectional area, and this can be written down at once in column (3) of the measurement record form shown at the end of this chapter.

Owing to certain climatic and other conditions, which will be explained later, it has been decided by the Forest Department in Burma that when constructing hillside roads a full width of 12 feet must be cut out of the hillside for cart-roads and a full 6 feet for elephant paths, regardless of the angle of slope of the hill; so the above method will give a correct estimate for all slopes. The dotted lines in fig. 41 show the cross-sectional area of the excavation, and it will be seen that this area is a triangle, with the base equal to the width of the road, and the vertical height equal to the reading on the template. Hence half the base multiplied by the height will give the area of the section.

When estimating for a 12-foot cart-road on the side of a steep bank, the horizontal 16-foot rod may come above the top of the 10-foot staff. The rod should then be held at 6 feet instead of at 12 feet, and this will bring it down within reach. The section given will now be

for a 6-foot road, and to obtain the approximate section for a 12-foot road multiply the result by *four*. This will not be quite so accurate as the direct measurement, but if the slope is fairly regular the result will be near enough for practical purposes.

A slope template is also very useful during road construction to measure the slopes of cuttings, and to check if they are according to specifications.

Measurement of two-sided cuttings and embankments. The depth of a two-sided cutting is estimated by setting the aligning instrument at the required gradient of the finished road surface and placing it on the last grade peg at the end of the cutting. The sight-vane is placed on the original surface of the ground above the cutting and in the middle line of the road. The distance between the point where the line of sight cuts the staff of the sight-vane and the height of the crosspiece on the sight-vane will then equal the required depth of the cutting.

The height of an embankment can be found in a similar way, but in this case it is better to raise the sight-vane itself from the ground until the crosspiece is in the line of sight and then measure the distance between the base of the staff and the ground. Where the depth of a cutting or height of embankment is irregular or changes rapidly, cross-sections should be taken at 10-feet intervals. In small embankments and where the height is fairly uniform throughout, the length of the intervals may of course be increased.

Where the upper surface of the cross-section of a cutting is very uneven, measure the depth of the cutting at the middle and at the two sides with the aligning instrument. The approximate average depth is then obtained by adding twice the depth at the middle to the depth at the two sides and dividing the result by four; e. g. in figs. 42 and 43, if the surface were irregular the average depth would be:

$$\frac{\text{Twice depth at C} + \text{depth at E} + \text{depth at F}}{4}$$

The shape of the cross-section of a two-sided cutting and of an embankment is the same. An embankment turned upside down would represent a cutting (see figs. 42 and 43). We can therefore measure them in the same way.

If the sides were vertical the area of cross-section would simply be the width multiplied by the height, but with vertical sides the banks would be continually falling, and therefore they are always sloped, the angle of the slope depending on the nature of the soil. The original banks will stand at a steeper slope in a cutting than the embanked or 'made' earth will stand on the sides of an embankment.

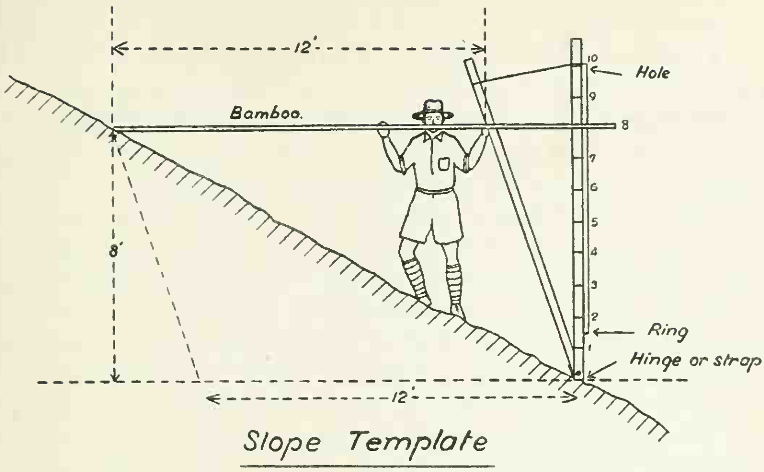


FIG. 41

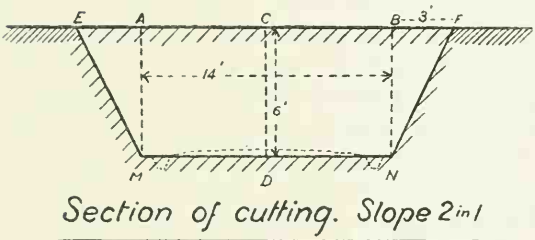


FIG. 42

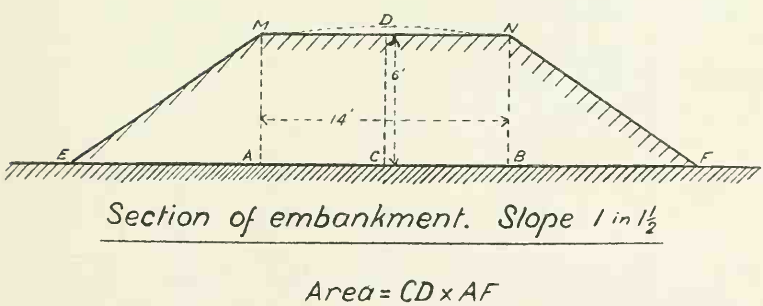


FIG. 43

A slope of 1 in 1 is usually considered sufficient for ordinary soils in a two-sided cutting, but a slope of 1 in 1½ should be used for unstable soils in a cutting and for ordinary soil in an embankment (see fig. 43). A slope of 2 in 1 is often used for good firm soil in a cutting for forest roads, and even 3 in 1 in the case of hillside cuttings, especially where it is necessary to save excavation to cut down costs. It should be remembered that *3 in 1* means 3 vertical units in 1 horizontal unit. This would be shown *1 to 3* in many books on engineering, but for our purpose it is considered better to use the same method of expressing the slope of a bank as for the grade or slope of a road, since we are already familiar with this method.

Cross-sections of a cutting and an embankment for a 12-foot forest cart-road are shown with two different slopes in figs. 42 and 43. It will easily be seen in these figures that triangles EMA and BNF are equal. Their combined area will therefore be equal to the base BF multiplied by the height BN or CD. The total area of the cross-section will therefore be CD multiplied by the sum of AB and BF, which equals $CD \times AF$. This may be expressed in words as 'The width of the road, plus the horizontal width of one side slope, multiplied by the height or depth of the embankment or cutting'.

The horizontal width of the side-slope equals the depth of the cutting divided by the given inclination of the slope. For example, in fig. 42 the depth is 6 and the slope 2 in 1, therefore the width of side slope is $\frac{6}{2}=3$. The width of road being 14 feet, we get the sum of 14 and 3 multiplied by $6=102$ square feet. In this way the areas can be very quickly calculated, but where there is much embanking or cutting to be measured it may be found convenient to prepare a small table similar to the example shown below, for quick reference.

CROSS-SECTIONAL AREAS FOR EMBANKMENTS OR CUTTINGS ON A FOREST CART-ROAD

Width 14 feet (12 feet, plus 2 feet allowance).

Height of bank or depth of cut.	Slope 2 in 1	Slope 1 in 1	Slope 1 in 1½
Feet	Sq. ft.	Sq. ft.	Sq. ft.
1	15	15	16
2	30	32	34
3	47	51	56
4	64	72	80
5	83	95	108
6	102	120	138

A similar table may be prepared for a 6-foot bridle-path.

In a two-sided cutting, an allowance of 2 feet is added to the width of a road for drains; and a similar allowance is added to the sides of an embankment to compensate for the loss of earth by erosion.

The above methods of obtaining the cross-section are sufficient for ordinary cuttings and embankments on forest roads, but for important cuttings on main roads or where special rates are necessary the cross-sectional areas should be carefully measured and plotted on paper, and the area obtained by means of a planimeter or with squared paper.

Total volume of earthwork and method of payment. Having obtained the cross-sections, the mean of two such sections at consecutive pegs is entered in columns (4) and (7) of the measurement record form. The cubical contents in columns (5) and (8) are then obtained by multiplying the mean section by the distance in feet between the pegs.

Earthwork should always be paid for at a fixed rate per 100 cubic feet excavated. For embankments the measurements are made in the 'borrow pits' from which the earth is obtained and not on the embankment where the volume would be much greater. The distance earth is carried is called the 'lead', and if the lead is more than 50 feet special rates will generally be paid, proportionate to the length of the lead. A lift of 5 feet is considered equal to a lead of 50 feet, and therefore lifts exceeding 5 feet will also entail special rates.

If the soil is very hard, or contains much rock which will require extra expense in blasting or removal, a note of this should be made in the remarks column, as extra rates will have to be paid.

Surface-dressing. If a cutting is less than one foot in depth, the work should be shown as 'surface-dressing'. This operation is sometimes combined with jungle clearing, but usually it comprises only the actual earthwork and the levelling of the road-surface. In the case of level sections it includes digging one-foot drainage channels along each side of the road as will be explained later when discussing road construction.

Surface-dressing should be shown in column (5) of the record form as '*SD*' and totalled separately at the end of each mile. A rate is usually fixed per 100 running feet.

3. CLEARING THE ROADWAY

Jungle clearing. There are various methods of measurement for jungle clearing, but it is customary to make a rough estimate for each mile of clearing. The rate paid usually includes the felling of all trees

under 3 feet girth, and the clearing of all small bamboos and undergrowth. This rate should be estimated and shown separately at the end of each mile on the measurement record form, as the cost of clearing will vary both according to the nature of the jungle and also with the slope of the ground. It will be the greatest on level country and least on steep hillsides. The question of the actual amount of clearing necessary under different conditions will be discussed in the next chapter.

Trees over 3 feet in girth which are not on the actual roadway but which it is necessary to clear, are felled at the ordinary local felling rates. These rates are usually fixed at a certain sum per running foot of girth for ordinary trees, and double rates are given for specially difficult and ficus-bound trees. The number of marketable trees of each species should be recorded in the remarks column, and summarized at the end of each mile.

Uprooting or grubbing out stumps. This should be estimated separately from the jungle clearing. The number of trees over 3 feet in girth, and full-sized bamboo clumps, which are on the actual roadway and have therefore to be grubbed out by the roots, are shown in columns 9 and 10 of the measurement record form. The present rate of payment in Burma for uprooting is about 4 annas per running foot of girth for trees, and Rs. 1 to Rs. 3 for bamboo clumps according to size. As already mentioned, these rates are given only as a rough guide, and the current local rates in each case must be obtained. The rates should include the removal of all timber and roots to a distance of 25 feet from the centre of the road-track, as this is a frequent cause of dispute with contractors. For the purpose of the road estimate a rough average cost per stump, to include both bamboos and trees, should be worked out from the rates being paid locally. From the above rates, which were obtained from estimates made in several different Forest Divisions in Burma, an average rate per stump of Rs. 1/8/- has been adopted in the sample estimate form at the end of this chapter. When preparing the measurement record in this way it is only necessary to count the number of trees and bamboo clumps, and their girth need not be measured until the work is finally approved and let out for contract. This simplifies the estimate form and saves unnecessary work.

4. ACQUISITION OF LAND

If the road crosses privately owned land which has to be acquired, a full description of the land must be given. In some cases compensation will have to be paid to cultivators for any damage or

VI. (*a*) Beginning excavation for hillside road.

(*b*) The same place several days later.

loss sustained, and a description of the state of cultivation and nature of the crop should be included in the report. The exact size of the area to be acquired should be given in acres, and the current local prices per acre ascertained. For a main cart-road a width of 80 to 100 feet is usually acquired, to allow for 'borrow pits' or future widening. Privately owned land will, of course, be avoided whenever possible when making an alignment, and the road should be kept on Government land even at the expense of a slightly longer route.

5. COMPLETION OF RECORD FORM AND ESTIMATE

For the items shown below reference should be made to the sample estimate form given at the end of the chapter.

(*a*) **Specification.** A specification for the road should be included with the estimate, stating the class of road proposed, the actual width of the finished road, and the angle of side slopes to be used for cuttings and for embankments. The type of bridges should also be specified, and the kind of timber to be used.

(*b*) **Gradient.** This is shown in columns 11 and 12 of the measurement record form. It may be shown in degrees or in horizontal equivalents, depending on the instrument used in alignment. For cart-roads for timber extraction the gradient should, if possible, be measured in the direction of the load, so that 'rise' will be *against* the load and 'fall' *with* the load.

(*c*) **Forward bearing.** Column 13. This is required only in level country where the alignment has been made with a prismatic compass. It assists in finding the line again if some of the alignment pegs have been destroyed. For ordinary forest roads a survey of the alignment is usually unnecessary.

(*d*) **Remarks column.** Note should be made here of all bridges and culverts, showing their estimated span: also of all marketable trees which are to be removed, giving the name of the species. The occurrence of rock or hard ground requiring special cutting or blasting should also be mentioned.

(*e*) **Drawings and maps.** Detailed drawings of bridges under 25-foot span are not usually made, but if required they are prepared after the proposed road has been provisionally approved. An average rate per foot, obtained from current local rates, is sufficient for the purposes of the estimate. Estimates and designs for large bridges are usually dealt with separately from the road estimate.

A skeleton map showing clearly the exact location of the alignment must accompany the estimate. A tracing from a standard 4-inch

map, showing the main streams and ridges and any existing roads, is sufficient for ordinary roads, with the proposed alignment marked in red. On large road projects, a longitudinal section or 'profile' of the road is prepared, but for surface roads of the type we are considering here, a profile is unnecessary.

(*f*) **Report.** A brief report giving the objects of the proposed road, mentioning any existing roads or possible alternative routes, should be submitted with the estimate. Particulars of land to be acquired and any special difficulties in the construction of the road should also be given.

(*g*) **Abstract of cost.** From the summaries at the end of each mile in the measurement record statement an abstract of cost for the whole road should be prepared, similar to the example given below. The abstract shows the estimated cost per mile under each heading and the total cost of the proposed road. The 15 per cent. allowance for *contingencies* covers the cost of drainage and extra cuttings, and also allows for incidental expenses such as the cost of transport of rice for coolies. Experience shows that at least 15 per cent. is necessary for road estimates.

A schedule of current local rates for earthwork, jungle-clearing, bridging, and all kinds of road work, should be maintained as already indicated, and this schedule should be used in completing the abstract of cost.

For important engineering works the earthwork is usually divided into several classes, according to its hardness, but for forest roads all earthwork is usually put into one class and a small extra rate paid for exceptionally difficult sections. Rock work requiring blasting should be dealt with under a separate heading. An example of an ordinary estimate for a forest cart-road is given below for reference. Only one sheet of the measurement record form has been included, but the abstract of cost on the following page is given complete.

ESTIMATE FOR THE CONSTRUCTION OF THEBYU—CHAUNGZU ROAD

Specification. 12-foot unmetalled cart-road from Thebyu to Chaungzu, in the Palwe Range, Pyinmana Division, Burma.

Estimate to include cost of clearing roadway; construction of all necessary timber bridges and culverts; and road drainage. Gradient not to exceed 1 in 20, except for short distances with the load. Actual horizontal breadth of cutting on hillsides to be 12 feet. Side slopes in average soil to be 2 in 1 for cuttings and 1 in $1\frac{1}{2}$ for embankments.

MEASUREMENT RECORD — Sheet No. 8.

Peg No.	Distance in feet.	Earthwork. Cutting. Cross-section at peg.	Cutting. Mean of 2 sections.	Cutting. Cubic contents.	Embankment. Cross-section at peg.	Embankment. Mean of 2 sections.	Embankment. Cubic contents.	Uprooting and clearing. Trees over 3 ft. girth.	Uprooting and clearing. Bamboo clumps.	Gradient. Rise.	Gradient. Fall.	Forward bearing.	Remarks.
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]
Carried forward		Sq. ft.	Sq. ft.	Cu. ft.	Sq. ft.	Sq. ft.	Cu. ft.						
..	..	..	..	72674	..	..	Nil	42	108	..	..	..	..
98	4988	59	..	..	..	..	..	..	..	..	..	..	..
..	58	..	63	3654	..	..	..	2	1	2·30	..	..	6 ft. culvert
99	5046	66	..	..	..	..	..	..	..	..	..	..	..
..	50	..	49	2450	..	..	..	..	2	2·30	..	..	..
100	5096	32	..	..	..	..	..	..	..	..	..	..	..
..	54	..	16	864	..	..	..	1	..	Level	..	..	1 Pyinkado
101	5150	0	..	..	..	..	..	..	..	..	..	..	..
..	47	..	..	S.D.	..	..	..	3	1	Level	..	..	..
102	5197	0	..	..	0	..	..	..	..	..	..	..	..
..	38	..	..	..	..	10	380	..	..	..	0·30′	..	1 Kanyin
103	5235	..	..	..	20	..	..	..	..	..	..	..	..
..	45	..	..	..	..	18	820	..	..	..	0·30′	..	..
104	5280	..	..	..	16	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..
Totals	5280	..	..	79642	..	..	1200	48	112	..	..	..	19 Teak 23 Pyinkado 14 Kanyin

End of First Mile.

Summary. Cuttings and embankments . . 80,842 cubic feet.
Surface dressing . . . . . 1,350 running feet.
Trees and clumps to be uprooted . 160
Estimated cost of jungle clearing, Rs. 48.
Bridges, one—20 feet span.
Culverts, five—6 feet span.

Example of Road Estimate (continued)

ABSTRACT OF COST

Number of Mile.	EARTHWORK. Excavation & Embankment. Cubic feet.	EARTHWORK. Excavation & Embankment. Rate per 100 cu. ft. Rs/-	EARTHWORK. Excavation & Embankment. Cost Rs/-	EARTHWORK. Surface Dressing. Length in feet.	EARTHWORK. Surface Dressing. Rate per 100 r. ft. Rs/-	EARTHWORK. Surface Dressing. Cost Rs/-	Jungle Clearing. Cost per mile. Rs/-	Grubbing out trees over 3′ girth, and bamboo clumps. No. per mile.	Grubbing out trees over 3′ girth, and bamboo clumps. Average rate per stump.	Grubbing out trees over 3′ girth, and bamboo clumps. Cost Rs/-	Bridges and Culverts. Span.	Bridges and Culverts. Rate per r. ft.	Bridges and Culverts. Cost Rs/-	Total Cost per mile. Rupees.
1st	80,842	1/-	808	1,500	1/-	15	48	160	1/8/-	240	1 Bridge 20′ 5 Culverts 6′	10/- 5/-	200 150	1,460
2nd	64,540	1/-	645	1,300	1/-	13	45	98	1/8/-	147	3 Culverts 6′	5/-	90	940
3rd	6,791	1/-	67	830	1/-	8	30	8	1/8/-	12	1 Bridge 26′	10/-	250	367
Totals	152,173		1,520			36	123			399			690	2,767

Total length of road, 2 miles, 528 feet.

Estimated Cost Rs. 2,767, plus 15 per cent. for drainage and contingencies, Rs. 415 = *Estimated Total Rs.* 3,182.

VI

FOREST ROAD CONSTRUCTION

1. ORGANIZATION OF LABOUR

THE amount and quality of work done will depend largely upon the way in which the available labour is handled. In engineering work it is just as necessary to study the labour as it is to study the materials used. Always make it a principle to get work started as quickly as possible. Select camp sites for the coolies near to their work and near to a good water-supply. For large parties of coolies it may save considerable delay to erect rough shelters before they arrive. Whenever possible get the work done by contract or piece work rather than by employing men on daily labour. Less supervision is required and the men work better.

Jungle-clearing should, as far as possible, be carried out separately from earthwork. If the labour is partly local, and partly Indian imported labour, use the local men for jungle-clearing and keep the Indian labour on earthwork.

An average forest cart-road costs about Rs. 1,000 per mile. One hundred coolies, earning an average of one rupee each per day, should therefore complete a mile of road in about ten working days. Divide the work so that not more than fifteen to twenty coolies are working in one gang. Lazy or poor workers are then easily detected and more work will be done than if the coolies are all crowded together. This can be arranged either by giving small contracts for separate sections of work or by dividing the coolies into separate gangs under coolie *gaungs* or headmen. If they are local men they will of course be divided into groups according to their villages. Each gang should be paid separately according to the work done.

Definite sections of road should be completed before a gang is allowed to move to another piece of work, otherwise the coolies may try to leave the more difficult parts and, after being paid for the easy work, will go away. The remaining portions will then have to be paid for at a special rate and measurement will be very difficult.

2. TOOLS REQUIRED

In most cases tools will have to be provided for the coolies, and careful arrangement must be made to ensure that the tools are ready before the work is started. Delays are frequently caused through

insufficient tools being available for the number of coolies employed. The following are the principal tools required for forest road work.

Native hoes (*paukbyas or mamooties*). For ordinary soil, every coolie should be supplied with one of these tools, and a surplus of 10 per cent. should be kept in hand to allow for breakages and loss. *Mamooties* are only intended for digging ordinary soft earth, and if used on hard ground or stones will at once get bent or broken. They should be purchased from a reliable firm as there are several cheap makes now on the market which will not stand hard wear, and which are often very brittle.

Grubbing mattocks (*or pauk-htus*). These mattocks are used for digging up roots and for breaking up hard ground, the soil being afterwards removed by ordinary *mamooties*. The number of grubbing mattocks required will of course depend upon the nature of the ground, but one mattock to five coolies is generally sufficient for average country, with an extra reserve of 20 per cent. of the total in case a bad patch of hard ground is met. Mattocks are shown in use in the photograph on plate VIII.

Pickaxes (*or pauk-kyuns*) are used for breaking up soft rocks, and for ground which is too hard for the grubbing mattocks. They are also used for digging out broken rock or small boulders. The number required will depend on the amount of rock and hard ground present. If a good supply of grubbing mattocks has been provided, only very few pickaxes are needed for average forest roads. Pickaxes are made of iron, on to which steel points are welded. One end is usually pointed, the other end is chisel-shaped. These points require frequent repair, and sufficient spares should be available so that a third of the total number can always be kept with the blacksmith for sharpening. Spare handles, or 'helves', for the above tools should not be necessary when working in the forests, as coolies should make their own helves when required.

Crowbars. These are for removing large rocks or tree stumps by leverage. In rocky ground two crowbars per gang should be supplied. If crowbars are not issued the coolies will often break and damage other tools through using them for heavy levering. Crowbars are easily bent and should be used with care, and large wooden levers should be substituted for crowbars when removing very large and heavy stumps.

Baskets. The coolies will usually make their own baskets from local bamboo. Baskets should only be used where it is necessary to carry the earth for a considerable distance. It is a very slow method

VII. Using sling baskets for removal of excavated earth during road construction.

of work, as a basket holds only from one-quarter to one-third of a cubic foot of earth, and half the coolies are usually standing idle all the time, since it is customary for one man to wait while his basket is being filled and then the other waits while the basket is being emptied. A good type of sling basket is shown in the photograph on plate VII. In Burma, head baskets are used chiefly by women and by Indian coolies, as Burmans prefer to carry sling baskets or bamboo stretchers. The construction and use of bamboo stretchers is shown on plates VI and VII.

For forming embankments from borrow pits and for deep two-sided cuttings, basket carrying is unavoidable, but for short distances, say under 25 feet, it is much quicker to pass the earth forward by a line of coolies with native hoes. This requires a little more energy and coolies will only do this if it is proved to them that they will earn more pay by this method.

Sledge-hammers. In rocky ground sledge-hammers and steel wedges are necessary for breaking up and splitting the rock. Sledge-hammers should be used for rock to save blasting whenever possible. Where blasting is needed, boring bars or jumpers will also be required.

String. A quantity of strong string or cord will be required for setting out curves and embankments. Cheap coconut-fibre cord is the most suitable, and is purchased by weight.

Saws and axes. For jungle-clearing and tree felling, native *dahs* will usually be provided by the coolies themselves, but cross-cut saws and axes will often have to be supplied. Two 6-foot cross-cut saws and four felling axes per gang are generally sufficient. Coolies should not be allowed to try to sharpen the saws, but when blunt, all saws should be given to a skilled man to prevent the set and pitch of the teeth from being destroyed.

Peavies. Peavies are wooden levers about 5 feet long, fitted with a hinged and curved iron arm the point of which grips the log when the lever is applied. They are very useful for rolling and removing logs and trees from the roadway during jungle-clearing.

Monkey-winch. This is an expensive but very useful instrument for pulling up stumps and removing trees. When pulling over a tree a log should be laid at its base so that the tree will trip over it and all roots will be pulled up. Four men working with a monkey-winch will do the work of about sixteen men in extracting stumps. The winch must be anchored firmly to the base of a sound tree or stump, and the end of the wire rope or cable should be fastened at a height of from 8 to 20 feet up the trunk of the tree to be felled. In the case of deeply

rooted trees, such as *gyo* (*Schleichera trijuga*), it is nearly always necessary to dig round the base of the tree and loosen the roots before the tree can be pulled over. A certain amount of practice and skill is necessary to use the winch successfully, and it should be kept in charge of a reliable man to avoid accidents. For big stumps and trees the snatch-block which is supplied with the winch should always be used, to increase the power and to avoid straining the winch. With the 'Trewhella' portable winch the set of ropes supplied will pull up trees 160 feet from the anchorage and a special 'Grab' is used to grip the rope at any length required.

Monkey-jacks are very useful in removing rocks and stumps of small trees. They are less expensive than a winch, but are much slower for general use. A firm footing, in the form of a rock or a wooden block, must always be placed beneath the jack.

Boning rods or boning staves. A set of boning staves consists of three rods or staves of equal height. For forest work they can be made on the site, from bamboo. The three rods, which are about 4 feet 6 inches in length, are each fitted at one end with a bamboo horizontal crosspiece, about 2 feet long, similar to the sight-vanes for Abney levels already described. Sometimes the boning staves are sharpened or fitted with iron points to enable them to be stuck into the ground and stand up without being held, and this is useful during road construction, when the surface has to be continually checked. When using them for fixing intermediate pegs in a road alignment, a staff is held on each of two adjacent grade-pegs, and the third staff is moved up and down between the other two until the tops of all three are seen to be on the same grade or level. See plates V and VIII. The point where the third staff rests will then be on the required grade. Thus any point between two grade-pegs can easily be checked by the three staves. Also any point beyond the grade-pegs can be similarly checked, if it is in a fairly direct line with the pegs and all three staves can be seen from one point.

Checking or grading with boning staves is much quicker and easier than with clinometers or other levelling instruments. Road construction contractors can quickly be taught the use of the staves in checking the level of the road surface, and in preventing coolies from digging below the required depth. Each gang on road work should be given a set of boning staves and be made to use them. Intermediate pegs can easily be placed between the grade pegs with boning staves, as explained above; and short bamboo pegs driven in at short intervals along the one-foot trace will ensure that the grade is kept even between the pegs.

3. METHOD OF CONSTRUCTION

Construction is not usually started until at least a year after the alignment has been completed, and the first step to be taken is to clear the one-foot trace and replace any missing or broken pegs. The measurement record form, which shows the distance and grade between the pegs, will be found useful in finding or replacing pegs which have been destroyed.

Distinct orders should be given to contractors and coolies that no pegs may be removed, and the ground for one foot around each peg must be left untouched, until the work is completed and measured up for payment.

Clearing roadway. Clearing should be carried out well in advance of the earthwork. After the jungle has been cleared it is often possible to straighten unnecessary small bends and adjust the alignment. Along the actual width of the proposed road all trees must be uprooted during the clearing, except on very steep hillsides, where the stumps will come out when the earth is excavated.

In the case of big trees it is always much better to uproot a tree than to fell the tree first and then dig up the stump, as the weight of the tree in falling assists in pulling out the roots; but small shallow-rooted trees under 3 feet in girth are sometimes more easily cut down and cleared at the same time as the undergrowth, leaving a number of high stumps which can easily be extracted when the earthwork is being carried out.

Sometimes the logging and dragging of the trees from the roadway is dealt with separately from the uprooting, but this should be avoided where possible and the rate paid for uprooting and felling should include the clearing. Where elephants or buffaloes are not available, big trees and heavy bamboo-clumps can be dragged away by a monkey-winch.

Old and dry stumps can usually be most easily destroyed by burning, but it must be seen that the whole of the roots and stump are properly burnt out, and not burnt only on the surface. Large stumps may often be split by iron wedges. It is not usually economical to employ explosives for extracting stumps except in specially hard and rocky ground and where explosives are already being used on the same road for rock blasting. The method of use of explosives will be explained later. No roots, stumps, or boulders must on any account be left embedded in the roadway.

Roadside clearing. When making cart-roads on level ground, a distance of 10 to 15 feet on each side of the 12-foot track is some-

times cleared of all undergrowth and of trees which are likely to shade the road. This side-clearing lets in the sun and air to dry up the road-surface, and the actual width of clearing varies in different localities. In the dry zone trees are necessary to shade the road. In other places the clearing of trees may be succeeded by a dense undergrowth, which will give more trouble than the original trees, and in sandy places the trees and bamboos along the sides of the road should never be cleared as sand makes a better and harder surface when moist. Very dry sand gets cut up by traffic and creates more resistance.

On steep hillsides a wide clearing on each side of the road is undesirable as the trees and undergrowth assist in preventing erosion. On the upper side of the road overhanging trees or trees which are likely to fall later, should be felled. Trees on the lower side should usually be left, except on very easy slopes where they overshadow the road. Above deep two-sided cuttings both sides of the road must be cleared of trees. All marketable trees felled must be properly logged and hammer-marked.

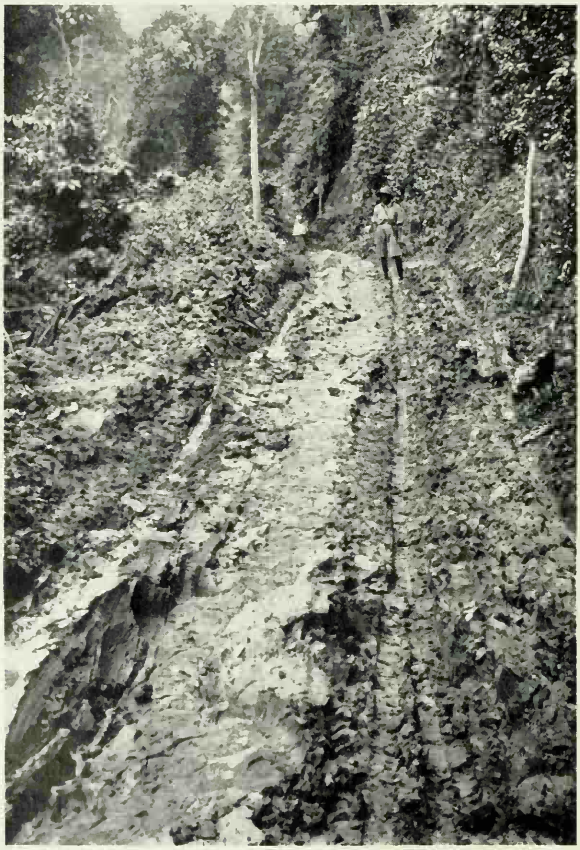
Surface-dressing. In level country, when all jungle clearing has been completed, all that remains to be done to form an earth-road is 'surface-dressing'. This consists in levelling off uneven parts of the ground, and filling up all natural hollows or holes from which stumps have been removed, with stone or well-rammed earth. For cart-roads in level country a drainage ditch should be dug along both sides of the road, throwing the excavated earth on to the middle of the road, which will give it a slight camber and assist surface drainage.

Hillside cuttings. On hillsides the road is formed by cutting inwards from the one-foot trace to a total width of 12 feet for cart-roads, and 6 feet for bridle-paths. As already mentioned, the specification for Forest Roads lays down that the full width shall be actually cut out of the hillside, and any gain of width resulting from the excavated earth is not to be taken into account (see plate VI). Owing to the heavy rainfall in most parts of Burma, most of this loose earth is washed away in course of time, unless it is held up by retaining or revetment walls, which would cost more to construct and to maintain than the amount spent on the extra excavation. If the full width is cut no revetments should be necessary, except on specially steep and rocky hillsides.

In rocky country, where the cost of excavation is very high and revetment walls can easily be built up from local stone, it may sometimes be more economical to reduce the width of the cutting. But timber and bamboo revetments, such as are sometimes seen on temporary

VIII. (*a*) Checking evenness of road surface with boning staves.

(*b*) Making a two-sided cutting through a small ridge.



IX. (*a*) Excavated soil being correctly levelled off during road construction.

(*b*) Badly-drained road resulting from depositing the soil on outer edge of road.

roads in hilly country, should rarely be used on permanent forest cart-roads, as they soon decay and always give trouble after a few years. In some cases the amount of money available does not permit of a full 12-foot cutting being made at once, and on easy slopes the width may have to be temporarily reduced, and cut out later during repairs.

The excavated earth from a hillside cutting must be completely levelled off, and no heaps of earth left above the surface-level of the road. If it is allowed to remain banked up on the lower side of the road it holds up surface-water and the road then becomes a water-course. It must be specified in any contract for roadwork that the rate paid per 100 cubic feet of earthwork includes the levelling down of the excavated soil. The photograph on plate IX shows the result of not levelling down the soil.

Road-construction coolies are fond of piling up logs or brushwood on the outer edge of a hillside cutting to hold up the loose earth and save themselves further digging, and will often move the alignment pegs outwards unless carefully watched.

It is important to see that the coolies never cut *below* the required surface-level of the road. Hollows made in the original ground surface cannot be filled up satisfactorily with 'made' earth, even if rammed, and always form low places which hold water later on.

Slope of banks on hillside cuttings. The angle at which the back slope will be cut depends chiefly on the nature of the soil, as already seen. For temporary roads, in order to keep down costs, the cutting is often made vertical wherever it will stand; but for permanent forest roads a suitable slope should generally be given, as shown in plate VIII (a). In the case of deep cuttings a good slope is more necessary than for cuttings of only a few feet in depth, and in the latter case the sides are often left vertical.

The slope at which any particular soil will stand after considerable exposure is called its 'angle of natural repose', and tables of angles of repose for all kinds of soils are given in engineering textbooks, but to use these angles for forest road-cuttings would cause unnecessary expense. We therefore compromise by making a slightly steeper slope than the 'natural' angle, and any subsequent small falls of earth which result from this are cleared away from the road during road repairs.

A slope template should be used to check the actual slope of the cutting when completed. This may vary from 3 in 1 in the case of firm well-drained clay soils, to 1 in 1 in the case of loose sandy soils. The slope shown on the right of the upper photograph on plate VIII

is about 2 in 1. It is important to see that the slopes are not made bulging, or 'bellied' in shape. A slightly concave slope is preferable.

In making deep two-sided cuttings the sides of the cuttings are usually cut either vertically or in steps, and the correct slopes formed afterwards. If any excavated earth is left on the banks of the cutting in the form of 'spoil banks' it must be thrown well back, leaving a clear space, or 'berm', of at least 3 feet from the edge of the cut slopes.

In order to ensure drainage, *an earth road through a deep two-sided cutting should never be made level.* It must be given either a steady gradient of at least 1 in 60 throughout, or a falling gradient from the centre of the cutting to each end. This must be done at the time of first construction, as it is almost useless trying to raise the middle of a cutting by throwing in loose earth afterwards.

4. EMBANKMENTS

Waterway. When forming embankments the chief essential is to see that sufficient waterway is provided for the passage of all water from intercepted streams or natural drainage. It is often difficult to estimate this during the dry season, when most embankments are constructed, but careful examination of the surrounding country will show the size of the drainage area from which the water will be collected, and high flood-level marks can usually be seen, or found through inquiry from local villagers. The height of the road surface should be at least 2 feet above the highest flood-level.

Intercepted water will pass through the embankment by means of either culverts or bridges. Frequent small bridges or culverts are usually better than a few large ones.

Laying out the site of an embankment. Before commencing actual construction the 'profile' of the finished embankment should be formed at short intervals along the alignment by means of bamboo or wooden stakes erected at the required height, and at a distance apart equal to the width of the top of the embankment. The tops of the stakes are then connected by a piece of thick string or cord. The ends of the cord are attached to pegs in the ground at each side, placed at the feet of the proposed slopes so that the cord will show the exact level and shape of the finished embankment and of its side-slopes. These profiles must be frequently checked as they are liable to be tampered with by the contractor or coolies. The usual side-slope of an embankment will be about 1 in $1\frac{1}{2}$, and should be tested by a slope template after construction. For embankments more than 2 feet in height the slope of the sides must be increased.

When constructing an embankment of ordinary surface soil an allowance of at least one-sixth of the height, or 2 inches per foot, must be added for subsequent settlement of the made earth. This allowance is for rammed earth, and for loosely piled earth double this amount is necessary. If gravel is used instead of soil the allowance can be reduced by half. The sides also will contract and get eroded, and, as already mentioned, an allowance in width of one foot on each side is necessary. If, for instance, a 12-foot cart-road is under construction mark out the top of the embankments at least 14 feet wide.

Borrow pits. The 'borrow pits', or roadside trenches, from which the soil is obtained for an embankment, should never be less than 6 feet from the toe of the embankment. They should be broad and shallow, generally not more than 3 feet deep, and the sides may be vertical or, if space allows, they should be cut in vertical steps, each step being one foot deep. Wherever possible, borrow pits should be drained into water-courses, so that water will not collect and stagnate in them. The ground allotted for digging the pits should be marked out with sides of 10 feet, or in multiples of ten, to facilitate measuring.

In all borrow pits, pillars of earth called 'witnesses' or 'dead men' are left at short intervals, at the level of the original surface, both for checking payment and to enable the average depth to be measured. 'Witnesses' must be removed at the time the work is measured up for payment, as coolies will sometimes clean out an old borrow pit containing witnesses and claim payment for it again. No measurements or payments should be made for borrow pits which do not contain witness-pillars or check-walls.

The points where witnesses are to be left should be selected previously and marked with a peg, as if left to the contractors or coolies they will select the highest points, and may even add a little to the height of the witnesses if not carefully supervised. The measurement for length and breadth should be taken at the bottom of the borrow pit.

Borrow pits may sometimes be made in the form of longitudinal drains on each side of the road, but if the ground has a considerable slope or is unstable it is usually better to make a series of unconnected pits, not more than 100 feet long, to avoid the formation of a stream near the road, which may cause erosion.

Materials. The soil used for embankments will usually be obtained from near the site, and choice of material is therefore very limited, but where possible the use of heavy clay, or soil containing vegetable mould and rubbish should be avoided. Gravel or shingle

makes the best embankment. The slopes of large embankments are often sown with grass seeds, and sometimes covered with turf, or terraced, to prevent slips and erosion.

Construction. When forming an embankment great care must be taken to break up thoroughly all clods of earth, or the bank will settle unevenly and later will be full of hollows. In the case of large and important embankments, and dams for water reservoirs, the earthwork is sometimes laid in a series of slightly concave layers, allowing one layer to settle before adding the next, the top layer being filled up and raised in the centre to form a slight camber to assist surface drainage, but this is very rarely done in the case of forest road embankments.

When the embankment is on a hillside, the original ground surface should be first cut out in a series of 'benches' or steps before beginning the embankment. This assists the new soil to bind with the original ground and prevents the bank from slipping down the hillside.

When an embankment is to be made over marshy ground, the ground should first be drained by frequent cross-drains, and by two longitudinal drains along the sides of the roadway. Brushwood or reeds should be rammed into the cross-drains, and if the surface of the ground is soft several layers of brushwood or poles should be laid down along the entire track to form a foundation before the embankment is started. The top layer of brushwood should be laid across the track and not parallel to the roadway. Where stone is available a foundation of large boulders is of course better than brushwood.

It is important to keep traffic off an embankment until the earthwork has properly settled. A good method of preventing carts from using the road is to delay the completion of bridges and culverts along the road until it is ready for use. Unless an embankment is built of clean gravel, sand, or stone, it should settle for one whole season before being used for traffic.

5. SPECIAL CONSTRUCTION

Irish bridges. These consist of shallow and broad causeways paved with stone, and are used for the purpose of carrying water across a road, either from an inside drain or where the road is crossed by a small stream. On main roads they are sometimes combined with a culvert as a safety overflow in case of heavy floods.

Irish bridges are only used on forest roads where good rock or stone is locally available. Stones, roughly faced, 12 to 18 inches long, 6 to 9 inches deep, and 4 to 6 inches broad, should be used. They are

placed on their edges, and laid with their lengths at right angles to the line of the road (see fig. 40). If bricks are used instead of stone they must be held together by mortar; but stones, if well shaped and fitted, do not need mortar or cement. Bricks are generally unsatisfactory for an Irish bridge.

The paved channel must be wide enough to take the water, but must also be shallow so that carts can cross easily without bumping. The outer bank of the road at the end of the paving must be protected against erosion by a short drop-wall of stone, the outline of which is shown in fig. 40. An Irish bridge should be sited in a level section of road. It should never be constructed across a road with a steep gradient, as it then forms a ridge in the roadway which is bad for cart traffic, and soon leads to the loosening and kicking up of the stones.

Corduroying. This is a method of using timber to form a more solid surface to a road over soft, marshy, or low-lying wet ground, and consists of laying down poles or logs across the roadway, side by side and close together. Poles from 5 to 10 inches diameter, and as nearly as possible of an even size, are generally used. Teak poles from thinnings should be used for the purpose where available, branches and prominent knots should be trimmed off, and only fairly straight poles selected. Larger-sized timber is sometimes used, and may be roughly squared or split in halves with the flat side placed downwards.

The surface of the ground must first be carefully levelled off and longitudinal side-drains dug along each side, deep enough to ensure drainage to the whole roadway; the earth from the drains being thrown on to the road-surface. Sometimes cross-drains are also dug and filled with brushwood, as already described in the case of the foundations for an embankment over marshy ground.

A foundation layer of logs placed longitudinally may be used on marshy ground, but generally a single layer of poles laid across the road from side to side is sufficient. For a 12-foot cart-road the poles should be cut 16 feet long; and over the ends of these poles after they are laid, are placed two lines of heavier poles called ribbands, laid longitudinally on each side of the road. This is to hold the corduroying in position. Where the corduroy poles are small and untrimmed the ribbands are usually pegged in position by pairs of short stakes. These are driven into the ground on both sides of the ribbands and slope towards each other so as to hold the ribbands firmly in place. If the corduroy poles are heavier and evenly trimmed the ribbands are usually spiked down to the poles themselves with long spikes. On wide roads a third ribband, generally split and with the flat side placed downwards, is often spiked down to the corduroying along

the middle of the roadway to keep the poles more firmly in position. The corduroying is usually covered with a cushion of earth about 6 to 9 inches deep. Sometimes a layer of straw or grass is spread over the corduroy before putting on the layer of earth.

Eight-foot corduroy tracks are often laid down to allow elephants or pack-mules to cross bogs and marshy places. A corduroy road is only a temporary expedient, as the poles will decay in a short time and require replacement. It also requires a large quantity of pole timber.

Guard-posts or Wheel-guards. These are timber-posts, or stone pillars, used on the insides of sharp curves or bends, and on bridge approaches, to keep the traffic from cutting off the corners and causing damage. They are also useful along the outer edges of hillside roads at sharp bends, and to protect roadside drains.

Timber-posts from 8 to 10 inches in diameter and about 5 to 6 feet long should be used, and at least half the post must be sunk into the ground. They should be sloped slightly outwards from the road and placed about 6 yards apart. Only sound, durable timber should be used for the posts, and their tops should be rounded off and the whole of the posts tarred before being put into the ground.

Retaining walls and breast walls. Retaining walls are required for bridge abutments and other places where it is necessary to hold up or retain a bank of earth at a steeper slope than that at which the natural soil will stand. We have seen above that, for ordinary forest roads, revetments and retaining walls should rarely be necessary, and are used only in very steep and rocky country.

Where walls are erected for the purpose of supporting original banks, such as the banks of a cutting on a hillside, they are called 'breast' walls. Breast walls are used for soils which are very unstable, or for banks which have to stand considerable pressure.

Rubble walls. For forest works the retaining and breast walls are usually made of unshaped stones. If all sizes are used indiscriminately, and merely fitted into each other's broken surfaces as closely as possible, the result is called 'rough' or 'random' rubble (see figs. 44 and 45). If the same type of stone is used, and, instead of mixing up the various sizes, pieces of like size are confined to one course and those of a smaller size to the next above, and so on, commencing with the largest and finishing with the smallest, the result is called 'coursed' rubble. A final course of larger-sized stones is added to the top of a coursed rubble wall, and each course is laid regularly and uniformly.

When a wall is sufficiently thick a 'facing' of coursed rubble is often used with a 'backing' of rough rubble. If large flat stones are

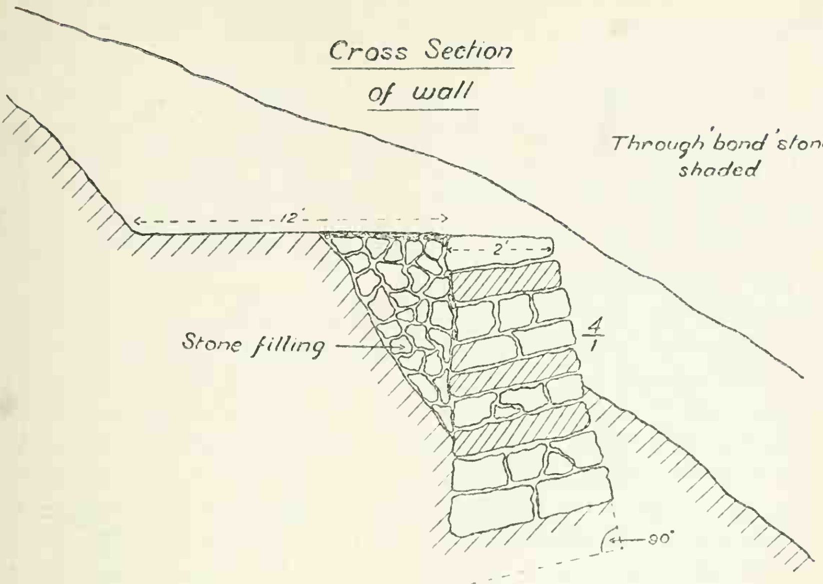

Cross Section
of wall
Through bond stones
shaded
12'
2'
Stone filling
4/1
90°

Fig. 44

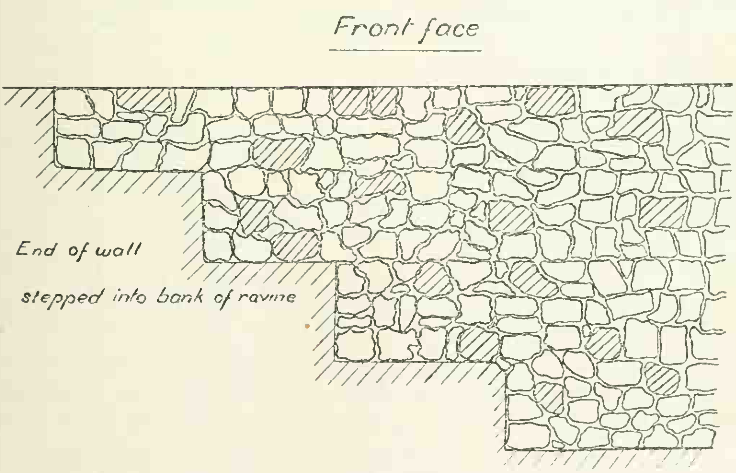

Front face
End of wall
stepped into bank of ravine

Fig. 45

available and they are carefully laid, a dry stone wall is usually sufficient, but where the walls have to resist much pressure they are greatly strengthened by using mortar to hold them together; and for very strong work cement is sometimes used in place of lime mortar, thus forming a kind of coarse concrete. If mortar or cement is used, or the stones are cut and fitted closely together, small openings must be left at frequent intervals to allow of free drainage from behind the wall. These openings are called 'weep-holes' and, unless there are sufficient of these weep-holes right through the wall, water is likely to accumulate in the soil behind it until the increasing pressure bulges out the wall and pushes it down.

Foundations and thickness of rubble walls. The foundations must be carried down into the original ground and must not be built on excavated earth. The foundation trench must be dug out so that the base will be *at right angles to the front slope* of the wall, as shown in fig. 45. The earth should be well rammed before the foundation layer is built. This foundation layer is made of the largest stones available. High walls require a base of masonry in mortar or of concrete 2 feet thick, but that is rarely necessary for the type of walling used on forest roads. The thickness of the wall depends on the weight of earth supported and the type of rubble used. The top of a dry stone wall should be roughly 2 feet thick, but if the wall is less than 4 feet high a thickness of 18 inches is sufficient. The additional thickness at the base will be proportionate to the height of the wall and will vary from one-quarter to one-third of the height, depending on the slope or 'batter' given to the face of the wall. This batter may be from 4 in 1 to 6 in 1 for breast walls, and 3 in 1 for dry stone retaining walls.

Construction. The back of the wall may be vertical, but for retaining walls no attempt should be made to build up a flat surface and numerous projecting stones are very desirable. Where a retaining wall is used to support a road crossing a small ravine on a steep hillside, the ends of the wall should be stepped into the banks on each side of the ravine in order to form a bond with the hillside, as shown in fig. 44.

If the stone can be squared or roughly 'dressed' a more substantial wall can be built; and where rubble or unshaped stones are used, large flat stones should be selected and laid with the flat side downwards, any crevices being filled with smaller stones or chips from blasted rock. The stones should be laid roughly in courses, even if a properly coursed rubble wall is not possible. Each course should be kept level longitudinally, and the base kept at right angles to the batter of the surface.

Long 'bond' stones, or 'headers', should be laid at intervals of 5 feet, chequerwise, as shown in fig. 45. They should be long enough to reach completely through the wall or, if too small, two stones may be used placed end to end. The whole strength of a dry stone wall depends on the weight of the stones and the friction between them, so stones as large as possible must be used and sufficient bond stones inserted to hold the wall together. Stone chips, gravel, or small stones and sand, should be filled in behind a retaining wall as 'backing', and ordinary earth should never be used for this purpose if it can be avoided.

Timber revetment walls. Where stone is not available, timber may have to be used for revetments. Roughly squared timber about 8 to 10 inches in width is the best, and small poles should not be used unless the work is required only for temporary purposes. Only durable species of hardwoods, such as *Pyinkado*, should be used, and all sapwood should be removed wherever the timbers are in contact with one another. The timber is placed horizontally on a firm foundation and held in to the bank by timber ties. These ties are placed about 5 feet apart and are notched or spiked to the walling timbers. They are let into holes 3 feet deep or are driven into the bank and should be kept at right angles to the face of the walling, which should be given a batter of about 1 in 6. Timber quickly rots in contact with the ground, and timber retaining walls need frequent replacement and are nearly always unsatisfactory. Where available, old steel rails make excellent ties or 'bonding' for both masonry and timber revetments.

VII

ROAD DRAINAGE AND METALLING

1. DRAINAGE

OWING to the heavy rainfall in most parts of the tropics, drainage is the chief consideration in all roadwork. It is especially important on unmetalled or earth-roads. The road surface is very easily eroded and destroyed by the action of running water; and if water is allowed to stand on the surface of an earth-road in ruts and hollows, the ground is softened and readily penetrated by traffic, which gradually deepens and enlarges the ruts until the road becomes impassable. Wheels with narrow rims increase the amount of damage by traffic, and carts with wheel rims of less than 2 inches in width should not be allowed on forest roads.

The aim of all road drainage should be to keep the surface of the road dry and hard, and free from surface water. The chief methods by which this aim may be realized are: (*a*) by sloping the road surface in such a form that water will be thrown off; (*b*) by providing water-channels to collect and divert water from the road; (*c*) by aligning the road on naturally well-drained ground and avoiding any unnecessary interruption of the natural drainage of the country; (*d*) by constructing a hard road surface with road metal or laterite; (*e*) by clearing away overhanging trees and undergrowth to allow the sun and wind to dry up the surface.

Surface Drainage (fig. 46). For hillside roads an outward slope is the simplest and cheapest form of surface drainage and requires least maintenance. The whole road is given a transverse slope of about 1 in 24, or 6 inches in a 12-foot road, towards the outer edge. No drainage channels are necessary as the surface-water simply flows across the road and, as no side-drain is required, the whole width of the road is available for the use of traffic. An outward slope is specially suitable for bridle-paths, as a side-drain soon gets filled up with earth and rubbish and becomes useless.

Outward slope drainage is not suitable for localities where the rainfall is very heavy, or for soils which are specially liable to erosion. In such places a transverse slope towards the hillside is sometimes made, but this entails a side-drain along the inner side of the road which is a great disadvantage, as will be seen later.

Sandy soils quickly absorb surface-water, and for roads containing much sand it is a mistake to arrange for surface drainage, since the

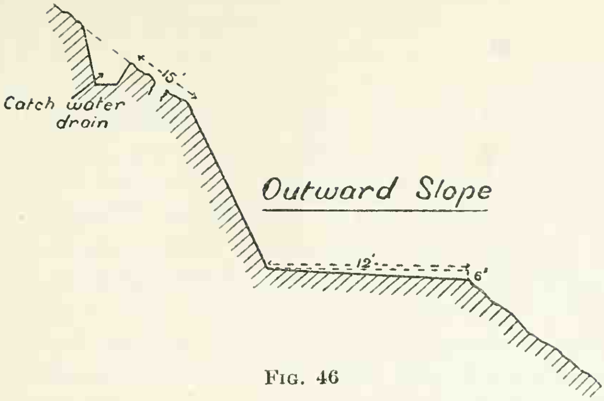


Fig. 46

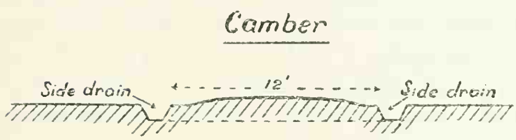


Fig. 47

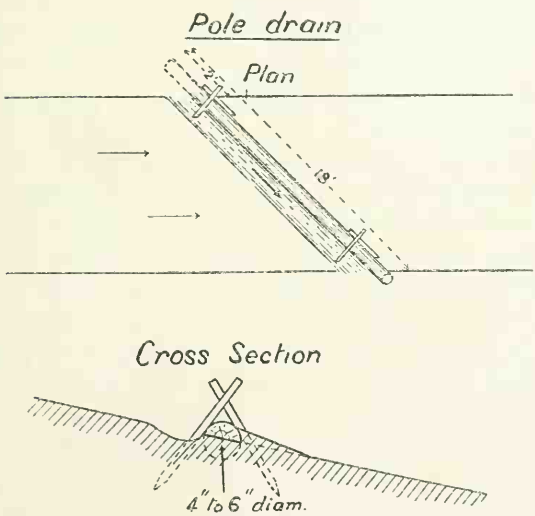


Fig. 48

wetter the surface of the road is kept the better. Sandy roads should be made quite flat, and trees and undergrowth should be allowed to grow near the road in order to conserve the moisture. For the temporary improvement of sandy roads use a layer of reeds, straw, grass, leaves, or any material that will accumulate and retain moisture and offer resistance to the wheels. For permanent improvement clay should be mixed with the sand.

Camber. In level country the drainage of the surface of the road may be attained by slightly raising the centre or crown of the road above the sides, as shown in fig. 47. A road shaped in this form is said to have a *cambered* or *barrelled* surface. The amount of camber and its form and shape depend upon the kind of road surface. Many various forms are given to the camber on main metalled roads, but for ordinary earth-roads it is sufficient to remember that the middle section of the road should be higher than the sides by about 6 inches. Bullock-cart traffic does not wear down the exact centre of the road but forms two ruts about 5 feet apart, and it is this width of track which should be kept raised.

All earth from side-drains in level country should be thrown on to the road, and the higher the road surface can be built up the less the danger of the road being converted into a water channel. The scraping of mud from earth-roads and throwing it away to the sides, which is often seen during road repairs, is not to be encouraged, as it steadily lowers the road surface level and more water will be collected. A better method of dealing with mud is by a road drag as will be explained later.

If a camber is given to a hillside road a drain on the inner side of the road becomes necessary. The great disadvantage of such a drain is that the water accumulates on the upper side of the road and still has to be carried across the road by expensive culverts or Irish bridges. The drain also lessens the effective width of the road, and extra width is very expensive on hillside cuttings. Also, unless protected by guard-posts, an inner drain soon gets destroyed or blocked up with earth, and then does much more harm than good.

Drainage of cuttings. Deep two-sided cuttings are the most difficult parts of a road to keep well-drained. Water from outside must be carefully diverted away from the cutting, and a 'catch-water' drain dug above the cut slopes, as shown in fig. 46. The surface of the road must be given a definite longitudinal slope in all deep cuttings, as explained in the last chapter, and side-drains are necessary on both sides of the road. These side-drains should be protected by guard-posts and revetted with brushwood where necessary.

Drainage channels and ditches. All drainage channels should be wide and shallow. The earth sides of deep narrow drains frequently fall in and block the drain, or the drain gets blocked with rubbish. A drain which is blocked causes much more damage than no drain at all, as the water accumulates and floods over the roads in small streams which soon cause erosion. The clearing of forest-road drains is often neglected during the rainy season, which is just when frequent clearing is necessary, and water from blocked or inadequate drains causes much serious damage to forest roads every year.

A good section for a small unlined roadside drain is 9 inches to one foot in depth, 2 feet wide at the top, with the sides sloping down to give a width of about 9 inches at the bottom. Drains of triangular section may be used in unstable soils. The chief point is to see that the sides are given sufficient slope. It is important that the soil dug out should be removed to a good distance from the edge of the drains, to avoid getting it washed back into the channels, and it should usually be thrown on to the middle of the road, as already mentioned.

The gradient of a drain needs attention. If it is too great the sides will become eroded and a stream will be formed. If it is too small the drain will be easily choked with small falls of earth or rubbish. A slope of about 1 in 120 is the best for an unlined drain. Where the sides are seen to be eroded owing to the steep gradient, the force of the water should be checked by steps at intervals along the drain. These may be made by putting in a big stone or rock, if available, but otherwise the step can be formed by letting in a short block of timber across the drain.

Sub-drains by underground pipes are rarely used on forest roads and where side-drains are used along a road the water should be led off at short intervals by outlets or 'run offs', so that it does not accumulate in the drains and overflow during heavy storms. The outlets frequently get blocked by rubbish and need frequent attention. In level country an old road or deeply-worn track running parallel to the new road can often be made to serve as a drain by making short connecting cross drains from the new road at intervals.

Pole-drains (fig. 48). These consist of poles placed obliquely across a hillside road to prevent an accumulation of water from running along the surface of the road, down the slope, and forming ruts and channels. They are a cheap form of drain, and are especially useful on long slopes on hillsides, where the surface-water tends to follow the wheel-ruts and deepen them into water-channels. Pole-drains should be placed at frequent intervals, say about every chain, along the slope, the steeper the slope the closer together. A pole-

drain is of little use at the very bottom of a slope. On bridle-paths they may be left in position all the year round, but on cart-roads they should be removed at the beginning of the carting season and replaced just before the commencement of the rains.

Poles about 4 to 6 inches in diameter and 18 feet long are used, and thinnings from a neighbouring teak plantation are very suitable where available. A shallow trench should be dug so that the pole is about half covered. The trench should be made in an oblique direction across the road, as shown in fig. 48, so that the pole slants outwards in the direction of the slope. They are sometimes seen sloping obliquely in the wrong direction which merely diverts the water towards the inner bank.

The pole is placed in the shallow trench and fastened down at each end by two strong pegs. On hillsides the inner end of the pole should be inserted for about 2 feet into the bank, which will hold it firmer than pegs alone. The earth from the small trench should be used as 'backing' on the lower side of the pole, as shown in the figure. Pole-drains soon collect silt, and the shallow trenches need very frequent clearing out. Where there is danger from erosion the bank just below the outer end of the pole should be protected by a few large stones. Where suitable stone is available a line of stone blocks may be used instead of a pole; although such drains are more expensive to construct they are of course much more permanent.

The above types of pole-drains are of no use on level ground, but the sides of deep drains along level roads may be revetted with poles, and such pole revetments are specially useful to protect the side-drains in deep cuttings.

Catchwater drains. These are drains which are made above road cuttings to prevent water from a hillside damaging the cut banks and the road below (see fig. 46). They should be made 15 feet away from the upper edge of the road cutting, and must be led out at frequent intervals into small ravines or existing streams which cross the road over Irish bridges, or are taken under the road by culverts or small bridges. If led out across the surface of the road they should cross at the ends of spurs to lessen the damage from erosion. Catchwater drains are particularly useful to protect the banks of deep cuttings, but as they are not easily inspected from the road they are often neglected and become choked with silt or rubbish, and for this reason they are generally considered unsatisfactory on forest roads. They are very liable to be choked with rubbish and falls of earth from the hillside, and should therefore be made wider than ordinary side-drains.

2. ROAD SURFACES

Most forest roads are earth-roads with no special surfacing. They are the cheapest form of road, but except on well drained soils or on laterite ridges where a good hard natural surface exists, they cannot be used by heavy traffic during the rainy season.

The two main objects of improving the surface of a forest road with other material are: (1) To extend the time during which the road can be used for the extraction of timber. (2) To create a harder and smoother surface which will give less resistance to traffic. Approximately three times the load can be drawn on a good hard metalled surface than can be drawn with the same power on ordinary earth-roads. The wear and tear on carts and other vehicles is also less, but for bullock traffic unmetalled roads are best.

Sand dressing. Where the amount of traffic is insufficient to justify the cost of a properly metalled road a considerable improvement can often be effected by sand or gravel dressing. On earth-roads containing a large proportion of clay, a top dressing of sand creates a better surface. Clay forms a very stiff form of mud, and the sand lessens the amount and the stiffness of this mud. The sand gradually gets mixed up with the clay, and more sand should be added each year until the road is satisfactory. A layer of 4 to 6 inches is sufficient at one time, as if more is used it becomes heavy for wheeled traffic in dry weather.

For ordinary cart-roads one *gyin*, which is 100 cubic feet, of sand is sufficient for 20 feet of road, spread evenly over the surface. About seven cart-loads are equal to 100 cubic feet. The sand can be obtained from any local stream bed, and the cost of hauling is therefore usually small.

Gravel dressing. Where gravel is available it forms a good hard surface for roads and paths. It should be passed through a screen or sieve, when possible, to separate the larger stones from the fine gravel. The large stones should be laid first and then the fine gravel on top. The gravel should be put down just before the rains so that it will get thoroughly consolidated before the heavy traffic begins. It should be rolled or rammed after spreading, and when the surface of the road is slightly wet and soft.

Long stretches of pure gravel surfacing are not often used for forest roads, as the gravel needs consolidation and is therefore more expensive than sanding; but gravel is very useful for the repair and improvement of roads. It may be used on heavy clay roads in the same way as sand surfacing and also for filling up deep ruts in earth-

roads, as will be explained below in the section on road maintenance. Fine gravel is also used as a 'binder' on the surface of properly metalled roads.

3. ROAD METALLING

When the surface of the road is made hard by a layer of broken stone thoroughly consolidated the road is said to be 'metalled' and the stone used is called road metal. Owing to the steady increase in the use of motor transport and the high cost of transport by railway of non-floatable hard-woods, and also the necessity for the extension of main roads to make new areas accessible, it is probable that many forest roads in Burma will be metalled in the near future. As already mentioned, a metalled road, by reducing the friction of the surface and by assisting drainage, enables carting to be continued all the year round and allows greater loads to be carried. The chief aim in road metalling is to provide a smooth, hard, durable, firm, and as far as possible watertight surface. Metalling is nearly always done by contract, and the duty of a Ranger will be chiefly to see that the work is carried out strictly according to the specifications of the contract.

Collection of stone. The stone from which metal is broken must be the soundest and toughest available. Sandstone is too soft, and flint is too hard to consolidate. A sample of the stone to be supplied should be deposited at head-quarters, with the name of the quarry from which it is obtained, and the signature of the contractor supplying the stone attached to it. The contractor supplying the stone is then responsible for its being in accordance with the specification and the sample deposited.

Stone from the surface of a quarry should not be used. The material must be clean and free from dust or rubbish, and the metal used on any one mile of road must be broken from the same stone. A mixture of hard and soft stones should never be permitted.

Every hundred running feet of road should have its full supply of stone stacked alongside for measurement. The sites of the stacks must be roughly levelled, and all stumps or rubbish removed before the metal is deposited. The material may not be stacked on the surface of the road, and a space must always be left free for carts. The stone may be either in the form of boulders or broken to the specification. The contract for the stone-supply will usually include special conditions regarding short stacking and rejection of bad material. Carting of stone should not be allowed during the rains or while the road is being consolidated.

Measurement of road-metal and stone. The stone must be

broken to pass through a $2\frac{1}{2}$-inch ring. Not more than 18 per cent. should be small enough to pass through a 2-inch ring in every direction, and not more than 20 per cent. should have its greatest measurement over 3 inches. The contractor supplying the metal must supply the necessary iron gauges for measurement when required.

All road-metal should be stacked and measured in rectangular boxes 5 feet long, 4 feet wide, and $13\frac{1}{2}$ inches deep, the $13\frac{1}{2}$ inches being measured as 12 inches to allow for settlement. Five boxes thus contain 100 cubic feet of stone. The contractor should give notice of his readiness to have the stone measured, and the measuring officer will then select sample stacks from any part of the work. A level piece of ground is selected on which a measurement box is placed. Near this box is erected a metal screen with $2\frac{1}{2}$-inch circular openings, or an iron-rod screen with square openings of 2-inch sides. The screen is set at such a slope that the specified $2\frac{1}{2}$-inch stone rolls slowly down it to the ground. All the material from the selected stack is gathered in baskets and poured slowly across the top of the screen. While this is being done, chippings which become jammed in the screen and any material which tends to block the openings of the screen should be removed. All stone which rolls down the face of the screen is thrown into the measurement box; all stone which is over size or not according to sample being carefully sorted out and removed. In order to measure the exact amount of good stone in the stack, four small boxes are sometimes used closed on all sides, and exactly one cubic foot in size. These are placed in the measurement box before any stone is thrown in, and as soon as the screened stone thrown from the stack exactly fills the measurement box one small box is removed. More screened stone is then thrown in until the box is again full, when another small box is removed, and this process is continued until all the good stone which is according to specification is finished. The volume in cubic feet of good stone in the original stack is then the volume of the measurement box *minus* the number of small boxes left in the measurement box.

Method of metalling new roads. The earthwork must first be made up to the finished level of the road, and must be properly drained and consolidated where necessary. The space to be occupied by the soling and metal must then be dug out of the surface, the depth depending on the thickness of the metal. The surface of the base of the excavation, which is called the 'sub-grade', should be given the same camber or 'barrelling' as that required for the surface of the finished metalling, which will be usually about 1 in 24. Any embankments should be allowed at least one rainy season to con-

solidate before metalling, and if the earth is soft after the required section has been formed it should be again rolled or rammed.

On embanked portions of road, and in other places where the earth is easily compressed or the soil is spongy, a foundation layer of specially large soling is usually required. This may be formed of tightly-packed bricks, large stones or boulders 9 to 12 inches in diameter, or blocks of limestone or other material. This heavy soling is expensive and should only be adopted where necessary. For ordinary ground a $4\frac{1}{2}$-inch layer of 3-inch soling-stone is generally sufficient. The stone is laid on the surface and well rolled in while dry, all hollows being made up and the surface finished off true to the required section of the completed road. Rolling is always better than ramming, and produces a more even surface. The soling should be made 6 inches wider on either side than the proposed surface width of metal.

On the soling-coat is laid $4\frac{1}{2}$ to 6 inches of $2\frac{1}{2}$-inch road-metal, which should be consolidated with a roller till all movement under the roller ceases, the stones being kept watered during the rolling. Water expedites the rolling but softens the foundation, therefore the quantity should be limited. Wooden templates, cut to the proper camber of 1 in 24, should be provided, and it must be seen that the road-surface is finished off true to template. The rolling should be done slowly, beginning at the sides and advancing to the centre.

As soon as the metal is consolidated to the proper section a half-inch topping of gravel or other material is spread and well flooded with water. The road is then finished off with a few turns of the roller over the topping. On no account should any topping material be added until the metal is thoroughly consolidated. When properly finished the wheel of a loaded cart should leave no impression, and the metal should feel tight and compact to the tread. If a contractor adds topping before the consolidation is passed by the officer in charge, the metal should be picked up, screened, and relaid at the contractor's expense.

The earth 'backing' on each side of the road should be neatly dressed level and flush with the metal and should be rolled where necessary.

The contractor should keep a new road in proper repair for three months after completion without further payment, the rate for new metalling being taken to cover the cost of such maintenance.

Remetalling existing roads. When a road which has already been metalled is due for metalling again it is important to ensure that the new metal will combine properly with the old. The same kind of stone should be used and from the same quarry if possible, as different kinds of stones will not bind well together.

The whole surface to be remetalled must be lightly picked over with a pick-axe. The amount of picking depends on the thickness of the old coat. All the necessary metal must be stacked alongside the road, and passed and measured before the spreading is commenced. The metal is spread in a layer, not exceeding $4\frac{1}{2}$ inches finished thickness, and before any rolling is done the surface must be dressed off true to the required camber, which as already mentioned is usually 1 in 24. For stone metal the roller must be at least four tons in weight, and the rolling must be continued until the wheel of a loaded cart leaves no impression. The metal must be kept well wetted during the rolling. On important roads the unrolled length of metal laid down should not exceed one furlong, unless an alternative road is available for traffic.

On each side of the road earth 'backing' at least one foot wide should be put down before the metal is laid to prevent it from scattering, and after the completion of the consolidation the backing must be made up to a width of at least 3 feet and laid level without an outward slope.

As soon as the metal is properly consolidated a half-inch topping of fine gravel or sand should be spread and well flooded with water, and the road is then finished off with a few turns of the roller.

The junction between the new and old metal surfaces must be graded down so that there is no sudden change of level along the road. The contractor should keep a road in proper repair for three months after completion of remetalling without further payment, as is done after metalling a new road.

Laterite roads. Laterite is a form of clay-stone containing iron, which gives it the characteristic reddish-yellow appearance. There are great differences in the quality of laterite, and it needs careful selection. It should be hard, dark in colour, heavy and compact in texture, and should not contain much pure clay; the mottled and streaked colours should be fairly evenly distributed. Laterite hardens on exposure, and should always be quarried and stacked in small heaps for at least a year before use.

When used for roads a 'soling' layer is usually laid first, consisting of laterite boulders not less than 6 inches in diameter. This is laid as evenly as possible, conforming to the camber of the road, and rolled while wet. The second layer is composed of broken laterite not more than 3 inches in size, and this is also rolled or rammed. A thin layer of sand 'topping' is then usually added, about $\frac{1}{2}$ inch in depth. If the laterite is used on a banked road, a good solid 'backing' of earth is necessary on both sides.

On the Bawbin road in Zigon Forest Division, Lower Burma, the laterite was laid on a road width of 11 feet, and 1,100 cubic feet of laterite was used per 100 running feet. The laterite, which was obtained at an average distance of three miles from the site, was supplied at the rate of Rs. 6/12/- per 100 cubic feet.

Laterite is locally available in many forest areas in Burma, and is therefore cheap, but it lasts only about two years under heavy traffic, and the cost of maintenance is therefore high.

4. ROAD MAINTENANCE

All roads require constant attention, and if small repairs are carried out at once more extensive repairs will be avoided later. A large proportion of the money and labour spent every year on repairs to forest roads could be saved if more attention was paid to early repairs and the maintenance of drains. As already mentioned, more damage is done to earth-roads through scouring and erosion by water than is caused by traffic.

Drains must be repaired at the beginning of the rains and *kept continually in repair* throughout the rainy season. The best time to inspect a road is during, or immediately after, heavy rain. Repairs to the road-surface should be carried out near the end of the rainy season while the ground is still soft and in a condition to consolidate. Labour is often wasted on unnecessary surface scraping to make it appear that a great deal of work has been done, and it is much better to concentrate the available labour and improve a short section of road thoroughly.

A Ranger has to prepare an estimate each year of the repairs required for the roads and paths under his charge. This estimate is made in the form of a tabulated statement in which a description is given of the exact location and the kind of road or path, the length and nature of repairs necessary, and the estimated cost. To assist him in preparing the estimate he should keep a large-scale map of all the roads in his range, indicating by colours the present state of the road, the sections where repairs and improvements are necessary, and also where work has been done during the current year.

Where deep ruts are being formed by cart-traffic it is often possible to divert the carts on to an unused portion of the road by putting large stones or gravel into the ruts at intervals, as draught animals will then avoid the original track, and a new track will be formed a few feet away. When filling up ruts or hollows, the surrounding road-surface must always be loosened with a pick to enable the new material to bind with the old.

Earth used for filling up ruts and hollows must never be dug out from the lower part of the bank of a cutting, but the upper part of the bank should be cut farther back to obtain the required earth. Under-cutting of banks during road repairs frequently causes the banks to subside and block the road during the following rainy season. The earth for repairs may also be obtained from drainage channels, but these drainage channels must be kept wide and shallow, and not merely deepened. Special attention must be paid to repairs of the drains in deep cuttings, and also on long hillslopes.

The use of a road-drag. A road-drag is a simple and inexpensive contrivance made of timber and used for the maintenance and improvement of the surface of earth-roads. It is also useful for forming a smooth and uniform surface on newly constructed roads and embankments.

A drag may be made of either round or converted timber, and the exact shape and size is not important. A suitable type of drag for forest roads is shown in fig. 49. This drag is now being used by the Public Works Department in Burma, and a similar type of drag was constructed by the Forest School students, in 1927, at a total cost of Rs. 30.

The drag consists of two light beams of timber about 8 feet long, parallel to each other, and held together by four ties of timber scantling so that the two beams are about 3 feet apart, with one end overlapping the other by about 12 to 16 inches. The construction can be seen from fig. 49. The parallel beams may consist of 4-inch planking, as shown in the drawing, or can be made from the two halves of a split log, 10 to 12 inches in diameter. Large and heavy beams should not be used, as weight is unnecessary and causes needlessly hard work for the draught animals. The lower front edge or 'toe' of the leading beam should be protected by a strip of iron, and this can be made from an old cart-tire or any other piece of iron about $\frac{1}{4}$-inch thick and 3 to 4 inches wide. When using split logs the iron strip should project about $\frac{1}{2}$ inch below the lower edge of the log.

The ties or cross braces are usually mortised and tenoned into the beams and fastened by nails or spikes, and one diagonal brace is added to stiffen the frame. Two long iron rods are used in the drag shown in the drawing, and this makes a very rigid frame, but iron rods are unnecessary in a temporary drag for use on forest roads. Two light planks are nailed to the braces for the driver to stand on.

Two dragging chains are necessary, each about 10 feet long. One chain is attached at both ends to the drag by means of eyebolts or

swivel bolts, which are bolted through the leading beam. The second chain is fastened at one end to the bullock yoke, and the other end is attached to the first chain, either by a simple knot or by means of a swivel bolt which is easily adjusted. By attaching the second chain at different points along the first chain, or by shortening one side, the drag is given the angle of skew required.

The chief object of the drag is to level down any irregularities in the road-surface and to fill up ruts or hollows. It is driven, at a slight angle, down one-half of the road at a time. This causes some of the loose mud and surface soil to be filled into the hollows, and the remainder passes along the front of the drag and is deposited in the middle of the road, forming a slight camber and assisting drainage. The return journey is made along the other half of the road, with the drag inclined towards the middle as before. This is shown in fig. 49.

If properly used, and at the right time, the drag will hasten the drying up of the road, and also save a great deal of labour on road repairs. The chief point to remember is that *dragging must be carried out only when the road is just sufficiently moist or soft.* A road drag should never be used on hard dry roads or on laterite. For successful working a little skill is necessary on the part of the driver, and it is probably owing to the difficulty of getting a good driver that road drags are not used more frequently on forest roads in Burma. The work is not difficult, but the driver must be induced to take an interest in his work or the drag may do more harm than good. The best way of inducing interest is by giving the driver extra pay for good work. Supervision will be necessary for the first few days, and then a driver may be given a section of road to maintain at a fixed rate per mile and should be able to work alone.

The drag is controlled and kept in position by the weight of the driver standing upon it. In soft places he should stand on the rear beam and in hard places on the front beam, and drive slowly. If the drag is too heavy or cuts in too deeply he should shorten the chains. To make the chains longer is equivalent to putting extra weight on the drag.

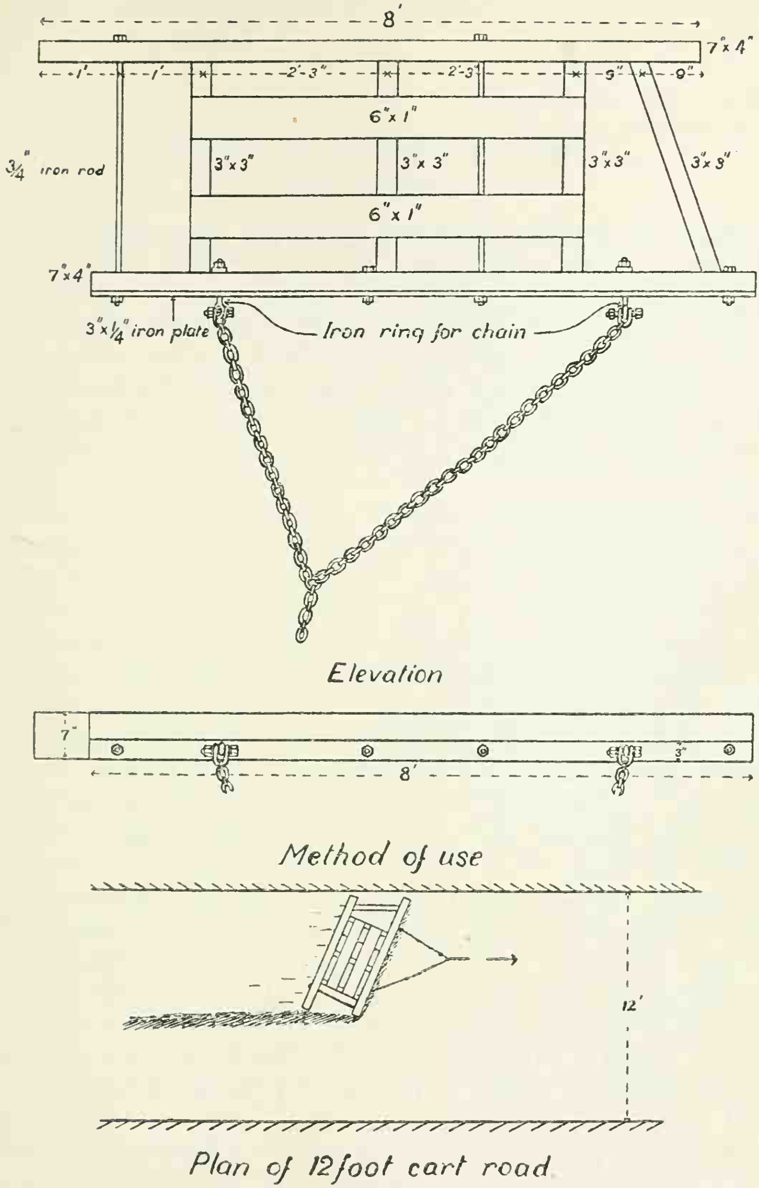

8'
7"x4"
1'
1'
2'-3"
2'-3"
9"
9"
6"x1"
3/4" iron rod
3"x3"
3"x3"
3"x3"
3"x3"
6"x1"
7"x4"
3"x1/4" iron plate
Iron ring for chain
Elevation
7"
8'
3"
Method of use
12'
Plan of 12 foot cart road

FIG. 49

VIII

SIMPLE WOODEN BRIDGES

1. INTRODUCTION

ALMOST all forest-road bridges in Burma are at present built of timber, and for small bridges on forest roads it is probable that timber will continue to be the chief material used for many years, although on main highway roads wooden bridges are gradually being replaced by iron, steel, and masonry. Timber is not an economical material to use for bridges of large span owing to the intricate form of trusses then required, as we shall see later; these large trusses are expensive to construct and are not nearly so durable as steel girders.

From an engineering standpoint all wooden bridges must be regarded as temporary structures which require periodical replacement, and the chief object is to make the bridges last as long as possible. In tropical countries we are very fortunate in having large supplies of strong and durable hardwoods, such as *teak* and *pyinkado* (*Xylia dolabriformis*) available in the forests. *Pyinkado* is the timber most commonly used for bridges in Burma and, if kept in proper repair and tarred regularly, a bridge constructed of a tropical hardwood of this standard should last about twenty years. Owing partly to faulty design and construction, and partly to external causes such as insect attack and fire, the average life of forest bridges is actually less than ten years.

As already indicated, for bridges in the forests a plentiful supply of good timber can usually be obtained near the site at comparatively little cost, and hence we are not obliged to consider economy in the use of timber so much as the durability of the bridges constructed. Our aim is to build a good solid bridge which will last as long as the timber of which it is built can be kept free from decay, and which is simple enough in design to be built by unskilled labour. Joints should be reduced to a minimum, as they collect moisture and are always the first parts of a timber structure to decay. Unless a saw-mill is near to the site it is more economical to use round timber than sawn timber for all the heavier parts of a bridge such as the girders and posts, as the only expense then incurred is for felling, dragging, and trimming. Thinnings from teak plantations, if available near the site, can be used for revetting the abutments and for wingwalls,

as will be explained below, but young poles, under 8 inches diameter at the butt-end, contain too much sapwood to be durable. Round poles are unsatisfactory for the decking of a bridge, as they do not give a good surface unless covered with earth, and any form of earth covering hastens decay. The bridge shown in the photograph on plate XI is a typical forest bridge and will be seen to answer some of the above requirements.

2. SELECTION AND PREPARATION OF BRIDGE SITE

The best site for a bridge is usually where the span is narrowest, and where the banks are well above flood-level and fairly equal in height. High vertical banks usually indicate firm stable soil and permanence of the stream channel. If the span is greater than 24 feet a crossing should be chosen where a good foundation for a trestle or pier can be obtained; rocky foundations are, of course, the best. A bridge should not be sited at a sharp bend in the stream or near a junction of two streams, nor where the stream is likely to change its course. Erosion is always greatest at the bends in a stream, and if it is found necessary to cross near a bend choose a site upstream rather than downstream from the bend. The bridge site must also be in a fairly direct line with the main direction of the road, as it is not generally worth making a long detour to get a slightly better site.

In hilly country it is important to ensure that the bridge will be easily accessible from both sides. The bridge should cross the stream as nearly as possible at right angles, and for a cart-road the level space on each bank must be wide enough to allow of a 30-foot log to be carted on and off the bridge. Any large trees close to the site which would overshadow the bridge should be felled before the bridge is constructed.

Stream training. Where there is special danger from erosion of the bridge abutments, due to the stream tending to change its course, it may be necessary to 'train' a stream, in addition to the direct protection to the bridge afforded by wingwalls and revetment walling. This 'training' usually consists of strengthening the banks upstream from the bridge and in leading the water into the required channel by guide-banks. For training works to be effective they must be commenced a considerable distance above the site of the bridge. The chief point to remember is that to turn a stream by direct opposition is almost impossible, and that the aim should be to *lead* the stream into the required channels. Stream-training is an art requiring a great deal of study if it is to be successful, and if bridge sites are properly selected it should rarely be necessary.

Stone and cribwork spurs. The usual method of diverting the current of a stream is by building out from the banks special obstructions, which are called spurs. The spurs check the force of the water and may give a new *set* to the current, but the total width of waterway must not be greatly reduced by spurs or the height of the water will rise and cause further trouble. The spurs are placed some distance upstream from the point to be protected, and may be built out from the bank either perpendicularly or at an angle with the current. Perpendicular spurs are useful against weak currents, but for streams with a high velocity it is generally considered that the spurs should make an angle with the bank of not more than 30°. Where stone spurs are used it is usually possible and often preferable to build them perpendicularly with the current, but timber and brushwood spurs are often too weak to resist the full force of the current and are built obliquely.

A quantity of silt is soon deposited both above and below the spur, and it has been found that, with streams of moderate velocity, a spur will protect a length of bank downstream five times its perpendicular distance from the bank, and three times the same distance upstream. A number of small spurs are better than one long spur, and the distance along the bank between the spurs should be approximately equal to the width of the stream. The tops of the spurs must be well above the highest flood-level. If the current of the stream is not very strong, two or more rows of posts or piles with bamboos interlaced may be used, the space between the rows being filled with brushwood, stones, gravel, or earth. The silt which gets deposited on either side of the spurs after a short time helps to strengthen them. If brushwood is used it must be firmly bound down by wire. The current tends to wash away or undermine the upstream corner of the outer end of the spur; this part is called the 'toe' of the spur and must be specially protected.

Where broken rock or stones of angular shape are available the spurs should be built entirely of stone, using the largest stones that can be obtained. The base of a spur should be slightly more than twice its height, and the top of the spur need only be a few feet wide. The toe of the spur should be strengthened and is often made of masonry, the remainder of the spur being formed of loose stones. If large angular stones are not available wooden crib frames are used filled with round boulders, and the cribs must be placed close enough together to prevent the stones from being washed away. A series of poles, about 8 inches in diameter, are laid in the form of a square frame, and are notched and spiked together as in the cribwork

trestle shown in fig. 58. Wire rope may also be used for tying the poles together. Long poles are laid along the bottom of the crib and attached to the sides to prevent the stone from being washed out if the spur is undermined by the current. The shore end of the spur must be carried well back into the bank, and the junction with the bank protected by stone facing.

If the stream contains deep water throughout the year, crib-work spurs may be made up complete on the bank and then floated out with a few large stones in the bottom. When the required site is reached they are sunk by filling them up to the top with large stones as before.

3. WATERWAY

The bridge-site having been selected and protected where necessary the next step is to estimate the waterway which must be allowed through the bridge, and this is often difficult. Sufficient waterway must be provided for the greatest flow of water that may be expected to pass during floods. The estimate is usually prepared in the dry season, and the only means of finding the highest flood-level is by the marks of floods on neighbouring trees and on the banks, and by inquiry from local villagers.

For ordinary streams the height of the bridge should be sufficient to give a clearance or 'freeboard' of at least 2 feet above the highest known flood-level, or H.F.L. For streams used for floating timber, or where the velocity and volume of the stream is great enough to bring down large pieces of timber and trees during floods, the clearance should be increased to at least 3 feet to prevent rubbish and timber from collecting beneath the bridge, or damage by floating timber striking the girders.

The span of a bridge should not usually be less than the average distance between the banks, and the span of small bridges can usually be roughly estimated by inspection and measurement of the width of the bed of the stream at the site.

For large streams and where the banks are not very clearly defined a more careful estimate is necessary. First find by inquiry the level of the highest flood ever known, and check the information by flood-marks if possible. Where the H.F.L. cannot be found by inquiry or from flood-marks a rough idea of the amount of flooding likely to occur during the rains can be got by studying the drainage area of the stream above the bridge on a map. If the drainage area is large and in bare hilly country, and if the rainfall of the locality is heavy, it can be assumed that high floods are likely to occur. If the country is level and covered with forests the flooding will be less. When the highest probable flood-level has been estimated, plot on squared

paper an accurate section of the bed of the stream, at right angles to the course of the channel, at the site of the proposed bridge, and calculate the area contained between the highest flood-line and the bed. Do the same at well-defined sections above and below the proposed site, and find the average area of the three cross-sections. The easiest method of measuring the cross-sections is by stretching a measuring-tape from bank to bank above the stream at the highest flood-level, and then measuring the depths at intervals of 10 feet with a long bamboo-rod marked in feet and inches and held vertically against the tape at each interval.

When you have fixed the height of the bridge, by allowing for the necessary clearance or 'free board' above the H.F.L., then the cross-sectional area divided by this height will give the required length of the span between the bridge abutments.

It is usually unsafe to reduce or restrict the natural waterway of a stream, especially in streams which are subject to heavy floods, but for very wide and shallow streams the span of a bridge must often be made less than the width of the original bed of the stream. In this case, by blocking part of the stream a rise of water or 'afflux' under the bridge will be caused, and an allowance for the increase in the depth of the stream must be made. The amount of the afflux will vary according to the velocity of the stream, and according to the proportion between the amount of obstruction and the natural waterway of the stream. For example, with a mean velocity of 5 feet per second, and an obstruction equal to three-tenths of the sectional area of the river, a rise of 6 inches will be caused. Tables showing the rise in feet for various velocities and amounts of obstructions can be found in any engineering pocket-book. The velocity of the stream will also be increased by the obstruction, and this may cause dangerous erosion of the bed of the stream, which may undermine the bridge abutments.

The above methods of estimating the span and waterway are very rough only, and common sense must be used in their application. For important bridges, engineers use special formulae for calculating the maximum discharge and the afflux of a stream, but these methods are too difficult for a Ranger to tackle, and are unnecessary for the small wooden bridges used in forest roads.

4. THE STRENGTH OF TIMBER BEAMS

The bridges usually constructed by the forest department are nearly all of a standard type, and it is beyond the scope of this book to deal with the calculations of the various stresses in a timber bridge and

their effect on the design. It is desirable, however, to know something of the action of forces and how to measure the strength of a simple timber beam.

[Readers with any knowledge of elementary mechanics should omit the next five pages which are only intended for junior students at the Forest School.]

It is first necessary to state clearly what we mean by the terms *force*, *load*, *stress*, and *strength*.

Force is any cause which produces or tends to produce or alter motion. The weight of a body is the amount of force which is exerted upon it by the attraction of the earth. Weight is therefore a convenient measure of force, and we speak of a force of 1 lb., 20 tons, and so on.

Loads and reactions. If a body is at rest all the forces on it must balance one another, as if they were not balanced the body would be in motion. If a post is placed upright on the floor and a load of 1,000 lb. is put on the top, the post does not move downwards, because it is prevented by the floor, which offers a resistance of 1,000 lb. The post therefore remains at rest under the action of the load of 1,000 lb. at one end, and the reaction of 1,000 lb. at the other. Similarly if a load of 1,000 lb. is hung from the end of a rod *AB*, fig. 50, the other end of which is attached to a beam, the rod does not fall because the beam offers a *reaction* of 1,000 lb. The load and reaction therefore balance each other.

Stress. In both the above examples the load is transferred through the post or rod to the point of support. The post or rod must therefore offer a resistance of 1,000 lb. at every part of its length. If it is not strong enough to do this, it will break. This internal resistance is called *stress*. In the case of the post it is a push or *compression*; in the case of the rod it is a pull or *tension*. If the rod *AB*, fig. 50, were cut through at the section *C*, the portion *CB* would fall unless a fresh external force of 1,000 lb. were applied upwards at *C*. Before the rod was cut, therefore, a force of 1,000 lb. must have been exerted by the fibres of the rod immediately above the section *C*. The same thing applies to every other section of the rod.

Factor of safety. Suppose the material of the rod to be teak-wood and that we find by a series of experiments that rods of teak, measuring 1 square inch in cross-section, break in tension with an average load of 10,000 lb. It follows that if we made our rod $\frac{1}{10}$ square inch in section, it would just break under the load of 1,000 lb. It is clear that for safety the cross-section must have a greater area than this.

In practice we should give an area at least five times as great, or $\frac{1}{2}$ square inch, and the cross-section of the rod might measure 1 inch by $\frac{1}{2}$ inch. We should then say that the factor of safety was 5, i. e. that the *working* load was only one-fifth of the *breaking* load. The strength of timber varies according to its quality even from trees of the same species, so the factor of safety for timber used in construction is generally raised to 7. The actual breaking load per square inch usually accepted for teak is 8,400 lb., and therefore the working load is 1,200 lb. For wrought iron and steel the factor of safety used is four, and for masonry it is five to seven.

Effect of length. If a set of specimens of any one kind of timber of various lengths be broken across in a testing-machine by a central load, we find that for specimens of the same cross-section the breaking load varies inversely as the length; so if the length between supports of one beam is, for example, twice that of another beam, the longer beam will break with only one-half the central load which makes the shorter one fail.

Effect of breadth and depth. Among specimens of the same length and depth, the breaking load is proportional to the breadth; while for specimens of the same length and breadth it is proportional to the *square* of the depth. When the load on a beam is concentrated at the centre the breaking load W which measures the strength of the beam, is therefore proportional to $\frac{bd^2}{L}$, where the breadth 'b' and the depth 'd' are conveniently measured in inches and L in feet.

In order to obtain the actual strength of a timber beam we must include a factor to represent the breaking load of the particular kind of timber used. This factor, which we will call k, is a number which is found by experiment to be the central breaking load in pounds of a piece of timber of the required species, 1 foot long and 1 inch square in section, supported at both ends. The breaking load W of a timber beam is therefore proportional to $\frac{bd^2}{L} \times k$. The values given for k vary slightly in different books, but for all practical purposes the following figures may be used for sound and seasoned timber of some of the commoner tropical hardwoods: *Padauk* (*Pterocarpus macrocarpus*) 864, *pyinkado* (*Xylia dolabriformis*) 836, *thitya* (*Shorea obtusa*) 740, *teak* (*Tectona grandis*) 730, and *pyinma* (*Lagerstroemia Flos Reginae*) 630.

These figures represent the value of k in pounds. Some books show the calculation in hundredweights, and the lengths L in inches, and care should be taken to see that the right unit is applied.

Forms of loading. If the load is distributed evenly along the beam, as in fig. 52, instead of at the eentre, the effeet of the load will be only half as great, and $\frac{W}{2} = \frac{bd^2}{L} \times k$. But if the beam is supported at one end only and earries a distributed load, as in fig. 53, the load has four times the effect as in fig. 52, and twiee the effeet it has in fig. 51, and $2W = \frac{bd^2}{L} \times k$. If the beam is supported at one end and loaded at the extremity, as in fig. 54, it has four times the effeet of the load as arranged in fig. 51, and $4W = \frac{bd^2}{L} \times k$. Henee, if we know the value of W for one form of loading and support, we can easily find the value for any of the forms shown in figs. 52 to 54.

We ean now find the working load of a simple beam of teak, loaded as in fig. 51, whieh is the same form of loading as the load of a eart on a bridge. We see from the above that for teak the value of k is 730. Then, using a factor of safety of 7, we get the working load $W = \frac{730}{7} \times \frac{bd^2}{L}$; or roughly, $105 \frac{bd^2}{L}$, for a teak-beam supported at both ends with the load eoncentrated at the eentre. For example, if b, the breadth of a teak-beam, is 6 inehes; d, the depth, is 10 inehes; and the unsupported length, L, is 18 feet; the working load $W = 105 \frac{6 \times 100}{18} = 3{,}500$ lb., or about $1\frac{1}{2}$ tons.

Since the strength is proportional to b, and to the *square* of d, the depth d of a beam should evidently be made as large as possible, but if the proportion is too great, the beam will not have suffieient stability, and will tend to warp or to fall over on its side. There are also other reasons for keeping the depth moderate, and the breadth of a well-proportioned bridge-girder should be about three-fifths of the depth.

Live loads. A suddenly applied load produees almost twiee the straining effeet of the same load applied gradually, and in bridge-work it is neeessary to distinguish between the 'dead' load and the 'live' load. The dead load eonsists of the weight of the permanent strueture, that is, of the bridge itself with its deeking; while the 'live' load consists of any moving loads sueh as men, animals, or earts whieh may eome on to the bridge. The dead load is usually evenly distributed over the bridge, but the live load, as for example a timber-cart, will usually be eoncentrated. As a general rule a live load should be treated as one and a half times the weight of a dead load. There

are several methods of estimating the effect of a live load more accurately, but the above rule is sufficient for our purpose.

Strength of round timber. The girders in forest bridges are usually of round timber, and for these we calculate the strength from the radius of the circular cross-section instead of from the breadth and depth. Where R = radius of the round section in inches, $4{\cdot}7R^3$ may be substituted for bd^2 in the above formulae.

As a practical example we will consider the girders of an ordinary forest bridge.

Four *pyinkado* girders, one foot diameter in the round, are supported at both ends over a clear span of 24 feet. It is required to find the safe working load that they will support.

The breaking load W of one girder $= k \times \dfrac{4{\cdot}7R^3 \text{ (inches)}}{L \text{ (in feet)}}$.

The value of k for *pyinkado* is 836, and therefore, with a factor of safety of 7, the working load will be equal to:— $\dfrac{836}{7} \times \dfrac{4{\cdot}7 \times 216}{24}$

Reducing the pounds to tons, we get:— $\dfrac{836}{7} \times \dfrac{4{\cdot}7 \times 216}{24} \times \dfrac{1}{2240}$

$= 2{\cdot}25$ tons (approx.).

For four girders the working load will be $4 \times 2{\cdot}25$ $= 9$ tons.

This is for a dead load, and for a live load which has $1\frac{1}{2}$ times the effect, the safe load will be $9 \times \frac{2}{3}$ $= 6$ tons.

(When estimating the actual external load which the girders of a bridge will support, it should be remembered that a deduction must be made for the weight of the decking and other superstructure, which is a dead load, and which will usually be distributed more or less evenly over the girders.)

In the above calculations we have so far only considered the resistance to *breaking* or the *strength* of a beam, but a beam must not only be strong enough to bear a load, it must also be *stiff* enough to bear the load without *bending.* The bending of a beam is called its *deflection.* The deflection considered by engineers as permissible in a beam under a permanent load is $\frac{1}{40}$ inch per foot of span, or 1/480, and for loads which are partly permanent and partly occasional, as in a bridge, $\frac{1}{20}$ inch per foot of span. For forest bridges where tropical hardwoods, such as *pyinkado,* are used it will be found that a beam which is strong enough to take the load is also nearly

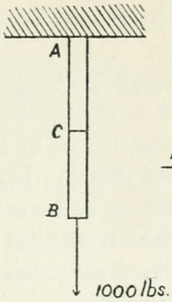


FIG. 50

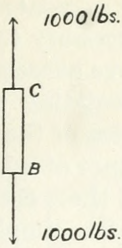
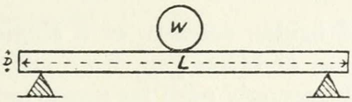
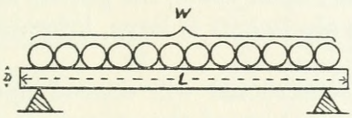


FIG. 51



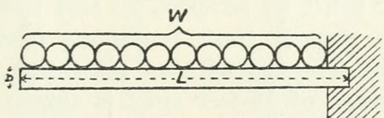
$$W = \frac{BD^2}{L} \times k.$$

FIG. 52



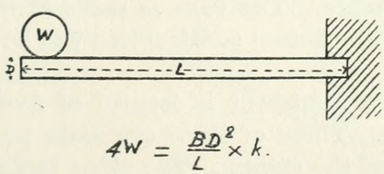
$$\frac{W}{2} = \frac{BD^2}{L} \times k.$$

FIG. 53



$$2W = \frac{BD^2}{L} \times k.$$

FIG. 54



$$4W = \frac{BD^2}{L} \times k.$$

always stiff enough. For more important bridges the deflection is always carefully calculated by engineers, by means of special formulae which it is unnecessary to deal with here.

From the above necessarily brief and incomplete description of the methods of calculating the strength of a timber-beam, a Ranger may get some idea of the effects of different forms of loading and the relative importance of length, breadth, and depth. It must be clearly understood that there are many other factors to be considered in the design of even the simplest structure which cannot be dealt with here, and that any departure from standard dimensions should only be made under the advice of a qualified engineer.

5. TYPICAL DESIGN FOR A SMALL BRIDGE

The simplest form of bridge consists of a single piece of timber stretched across a stream, or other gap, from side to side, and this primitive bridge is still commonly used for forest paths. An ordinary girder bridge is merely a development of this simple crossing. Several beams or girders are laid side by side, and a decking or *superstructure* is added to form the roadway. The banks on each side are strengthened to form *abutments*, upon which the girders are supported, and if the span between the abutments is large, intermediate supports or *piers* are added.

The type of bridge constructed will depend upon the span, the natural foundations, the nature of the stream or other obstacle to be crossed, and the kind of traffic for which it is required. The simple timber bridges described below are suitable for ordinary sites and for forest roads, but no two bridge-sites are exactly alike, and the form of every bridge must be adapted to suit the local conditions. Bridges differ in this respect from buildings, where standard type designs can usually be followed without alteration.

A typical small bridge of 20-feet span is shown in fig. 55. This kind of bridge is now used for forest roads throughout Burma. The photograph on plate XI shows a forest bridge of exactly the same type, but with a support in the middle. The width of the bridge is 12 feet from centre to centre of posts, which gives a clear width of roadway of about 10 feet 6 inches. The various parts of the bridge will be explained below, and the actual construction will be dealt with in the next chapter.

Abutments. Each abutment is formed of five *pyinkado* posts, one foot in diameter. Three of these are main posts and are sunk 4 feet below the bed of the stream. The other two posts support the

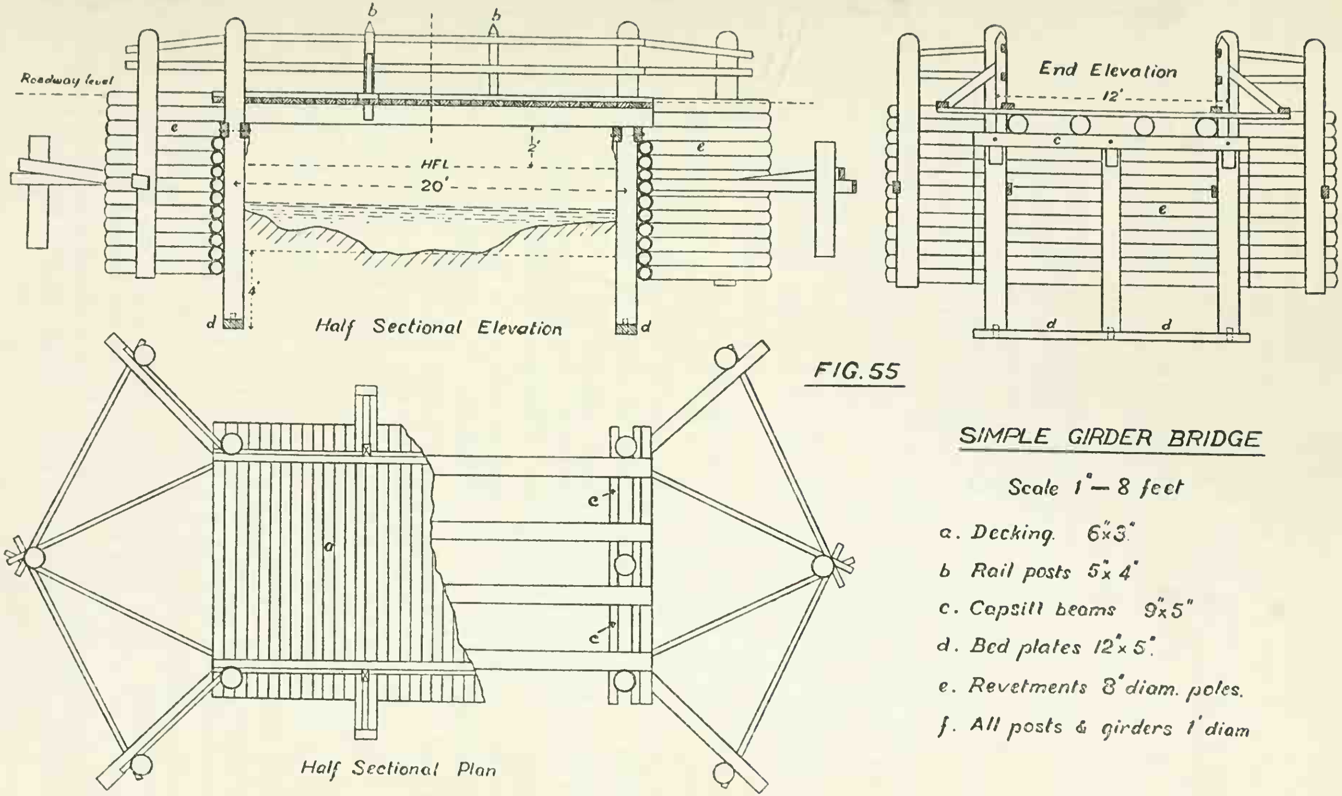


FIG. 55

SIMPLE GIRDER BRIDGE

Scale 1" — 8 feet

a. Decking. 6"x3".

b Rail posts 5"x 4"

c. Capsill beams 9"x 5"

d. Bed plates 12"x 5".

e. Revetments 8" diam. poles.

f. All posts & girders 1' diam

wingwalls, which are splayed back according to the formation of the banks. No stone was available near the site, or the banks would be sloped and faced with large-sized stone, as this forms a much more durable abutment than wooden wingwalls. The abutments and wingwalls shown in the drawing are revetted with round poles, 8 inches in diameter, from the thinnings of a neighbouring teak plantation. Note that these revetments are carried down well below the level of the bed of the stream.

The posts are anchored back by wooden ties to a firm anchorage post, sunk into the ground at a distance of 12 feet from the edge of the bank (see plate X). Owing to the large diameter of the posts, diagonal bracing between the posts was not found necessary. The three main posts rest on a bedplate of 12×5 inch timber, and are kept in position on the bedplate by round tenons $2\frac{1}{2}$ inches in diameter, made on the lower ends of the posts, and fitted into mortises or holes bored in the bedplate. This method is called 'joggle' jointing. The tenons on the posts are sometimes difficult to make, and an alternative method is to use dowel pins, which fit into holes bored in the posts and in the bedplate. The bedplate should rest on a foundation of rammed stone where this is available.

The abutment posts support the 'transoms' or 'capsills' on which the girders are placed. Two capsills of equal size (9×5 inches) are bolted into notches cut to receive them on both sides of the posts, a cleat is added beneath to strengthen the joint.

Girders and superstructure. The girders are of round *pyinkado* timber, one foot in diameter. The span of the bridge from centre to centre of posts is 20 feet, and therefore the distance between the two outer edges of the posts is 21 feet. The girders are cut 23 feet long, so that they project one foot beyond the posts at each end.

The superstructure consists of the decking and handrailing. The decking is of 6×3-inch planking, fastened in the middle with 6-inch spikes directly to the girders. The ends of the planks are held down by two ribbands, or 'kerb plates', also of 6×3-inch planking, running along each side of the bridge and bolted down by $\frac{1}{2}$-inch bolts. The rail-posts, four of which are main bridge posts, and the remainder intermediate posts of 5×4-inch timber, are notched at the base 2 inches deep for the ribbands, these notches helping to keep the latter in position. The intermediate rail-posts, which are 5 feet long, are carried down through the decking, and are spiked firmly to the outer side of the girders below. Two of the decking planks adjoining each rail-post are prolonged for 2 feet on both sides of the bridge to receive the rail-post struts.

SIMPLE GIRDER BRIDGE FOR FOREST CART-ROADS. Width 12 feet. To carry five tons.

STATEMENT OF MATERIALS

[For type design of this bridge see fig. 55]

Serial No.	Item.	12-foot span.				16-foot span.				20-foot span.				24-foot span.			
		No.	Length in feet.	Breadth in inches.	Depth in inches.	No.	Length in feet.	Breadth in inches.	Depth in inches.	No.	Length in feet.	Breadth in inches.	Depth in inches.	No.	Length in feet.	Breadth in inches.	Depth in inches.
	Sawn timber.																
1.	Decking	24	14	6	3	32	14	6	3	40	14	6	3	48	14	6	3
		2	18	6	3	2	18	6	3	4	18	6	3	6	18	6	3
2.	Ribbands	2	14	6	3	2	18	6	3	4	13	6	3	4	14	6	3
3.	Capsills	4	14	4	8	4	14	5	9	4	14	5	9	4	14	5	10
4.	Bedplates	2	14	12	5	2	14	12	5	2	14	12	5	2	14	12	5
5.	Rail posts [Intermediate]	2	5	5	4	2	5	5	4	4	5	5	4	6	5	5	4
6.	Railing	8	9	2	4	8	9	2	4	8	9	2	4	8	9	2	4
		4	14	2	4	4	18	2	4	6	15	2	4	8	14	2	4
7.	Rail post struts	2	5	6	3	2	5	6	3	4	5	6	3	6	5	6	3
8.	Anchorage ties	8	14	6	3	8	14	6	3	8	14	6	3	8	14	6	3
9.	Cleats	6	2	6	3	6	2	6	3	6	2	6	3	6	2	6	3
		Total cu. ft. sawn timber =61·4				Total cu. ft. sawn timber =116·0				Total cu. ft. sawn timber =144·4				Total cu. ft. sawn timber =169			
	Round timber.																
10.	Girders, 1′ diameter	3	15′ long			4	19′ long			4	23′ long			4	27′ long		
11.	Posts, 1′ diameter	12	Length as required			12	Length as required			12	Length as required			12	Length as required		
12.	Revetment walling		5″ to 8″ diam. poles				5″ to 8″ diam. poles				5″ to 8″ diam. poles				5″ to 8″ diam. poles		
	Ironwork.																
13.	Bolts and nuts [for Ribbands]	6	½″ × 6½″			8	½″ × 6½″			12	½″ × 6½″			16	½″ × 6½″		
14.	Bolts and nuts [for Capsills]	6	¾″ × 18″			6	1″ × 18″			6	1″ × 18″			6	1″ × 20″		
15.	Spikes 4″	10 lb.				15 lb.				¼ cwt.				¼ cwt.			
	,, 6″	1 cwt.				1 cwt.				1½ cwt.				2 cwt.			
	,, 7″	¼ cwt.				½ cwt.				½ cwt.				½ cwt.			
16.	Coal tar	5 gallons, or as required				7 gallons, or as required				10 gallons, or as required				15 gallons, or as required			

The rails are 2 × 4-inch scantlings, and are spiked to the railposts, which are notched to receive them. The height of the top rail above the decking is 3 feet 3 inches.

It is always preferable to use timber of the same dimensions throughout a structure if possible. Odd lengths can then be used up and wastage reduced. Hence in this bridge 6 × 3-inch timber is used for all decking, ribbands, ties, struts, and cleats.

Statement of materials required for small timber bridges. The quantities of timber and other materials required for simple girder bridges of the type shown in fig. 55, for spans of 12, 16, 20, and 24 feet, are given in the statement of materials on p. 135. The dimensions given are for first quality *pyinkado* timber. Owing to the difficulties of extraction of all heavy hardwoods, sawn timber of more than 20 feet in length is often unobtainable, and in the statement of materials no lengths over 18 feet have been included; where a greater total length is required an allowance for the overlapping of joints has been added. The lengths of the posts and the number of revetment poles will depend on the depths of the foundations required. This will also affect the quantity of nails and amount of tar, which must be adjusted accordingly. Bed-plates, shown in item No. 4, are of course not required if the posts are to be pile-driven.

It should be noted that the statement of materials is only intended to serve as a general guide, and every bridge must be adapted to suit the actual conditions found on the site. This particularly refers to the abutments and foundations.

IX

CONSTRUCTION OF BRIDGES AND CULVERTS

1. DETAILS OF CONSTRUCTION

Marking out site. All bridge abutments and piers must be set out parallel to the main direction of the stream and to each other. Where the line of direction of the road is such that the roadway of the bridge cannot be set out exactly at right angles to the abutments, without causing a sharp S-shaped bend in the road, a 'skew' bridge is built. Skew bridges are difficult to construct, and can usually be avoided by careful selection of the bridge site.

When marking out the site, the first step is to mark out by pegs the line of the abutments exactly parallel with the current of the stream. As the ground on the actual site of the bridge abutments will be excavated, the marking-out pegs are placed in prolongation of the lines of the posts in both directions, so that strings stretched from these pegs will cross at the exact sites of the posts, and after excavation, plumbobs dropped from these points of intersection will fix the exact sites of the bedplates.

Bridge approaches. The approaches to the bridge must be raised well above the highest flood-level. For at least 10 feet at each end of the bridge the approaches should be level, and the grades for the remainder of the distance should not exceed the maximum gradient of the road. Traffic tends to wear a hole about 2 feet from the ends of a bridge, and this part of the approach must be well rammed, and filled with stones or gravel where available. Sharp bends in the approaches to a bridge should be avoided, and, where bends are necessary, place sufficient guard-posts round the inner side of the bends to protect the bridge. All road-drains must be led out into the stream at a safe distance from the bridge; in hilly country the neglect of this precaution is a frequent cause of erosion of the bridge abutments.

Foundations. Firm foundations are essential for all bridge abutments and piers, and inattention to this is the cause of the majority of the failures of forest road-bridges. Foundations cannot be inspected after the bridge is completed, and when bridges are built by contractors it is important that the bedplates or other foundations are seen *during construction* and before the earthwork is replaced.

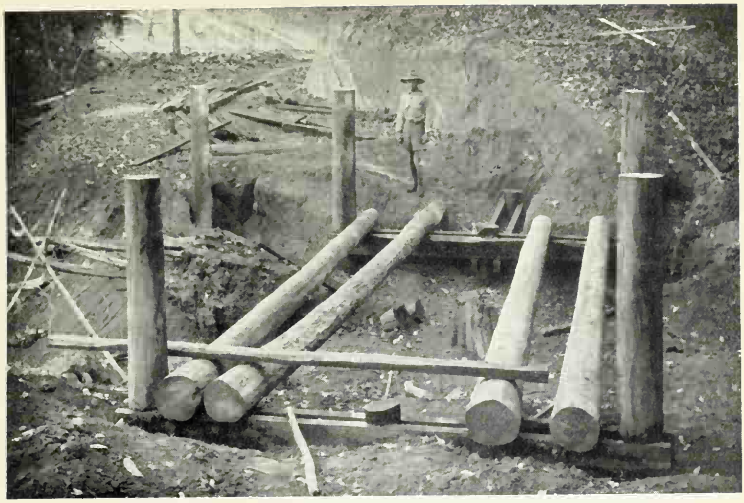
The use of bedplates for bridge abutment-posts was explained in the last chapter. Where the presence of water or loose wet sand prevents excavation to the necessary depth for bedplates, the posts are driven into the ground, and are then called 'piles'.

Piles. Timber used for piles must be carefully selected. The posts must be sound, free from large knots or shakes, and straight in grain. All sapwood must be trimmed off, and one end of the post brought to a blunt chisel-shaped point. Long finely pointed piles are unsatisfactory, as they are likely to break or glance to one side if they meet with large stones or other obstructions. In soft silt a square-ended unsharpened pile is often used and is found to drive more truly. With hardwood piles for forest work in ordinary soil it is very rarely necessary to use iron points or 'shoes', but where shoes are required it is important to see that they fit closely. If the shoes are badly fitted the strain comes directly on to the bolts or spikes used to fasten the shoes to the piles, and this frequently causes the piles to split.

It is important to see that the head of the pile is cut quite square and level, or the blows of the pile-driver will be received on one edge and the pile will probably split. To protect the head of the pile when being driven, an iron ring, about 2 inches deep by ½ inch thick, should be fitted. The outside of the pile is slightly trimmed down for a few inches near the end, so that the ring will easily slip on to it, and after two or three blows from the monkey the ring will be found to be tightly clasping the timber. The top of the ring should be flush with the head of the pile. With hardwood timber there is usually very little crushing or 'brooming' of the head of the pile. If the pile splits in spite of the ring, the broken head is cut off and a new ring fitted. It is often difficult to estimate the required length of the piles until the first pile is driven, and this should be carefully measured and used as a test pile.

Pile-driving. There are many forms of 'pile-drivers,' ranging from a maul raised by two men and dropped repeatedly on to the pile, up to large machines with heavy rams weighing several tons and worked by steam.

The type of pile-driver most commonly used consists of a weight called a 'monkey', with a rope attached, which passes over a pulley fixed on a high vertical frame. See fig. 56 and the photograph on plate XI. When the rope is pulled the monkey is raised until it reaches the top; it is then allowed to fall by its own weight on to the head of the pile. This action is repeated until the pile is driven into the ground. If the site of the work is near a main road or railway, and there are a large number of piles to be driven, a proper pile-driver



X. (*a*) Small 16-ft. span bridge under construction, showing split-capsill beams on post abutments.

(*b*) A bridge abutment with pile-driven posts, showing trenches for anchorage tie-beams.

XI. (*a*) A simple form of pile-driver being used in bridge construction.

(*b*) A forest cart-road bridge with girders and posts of round timber and with a pile-driven trestle.

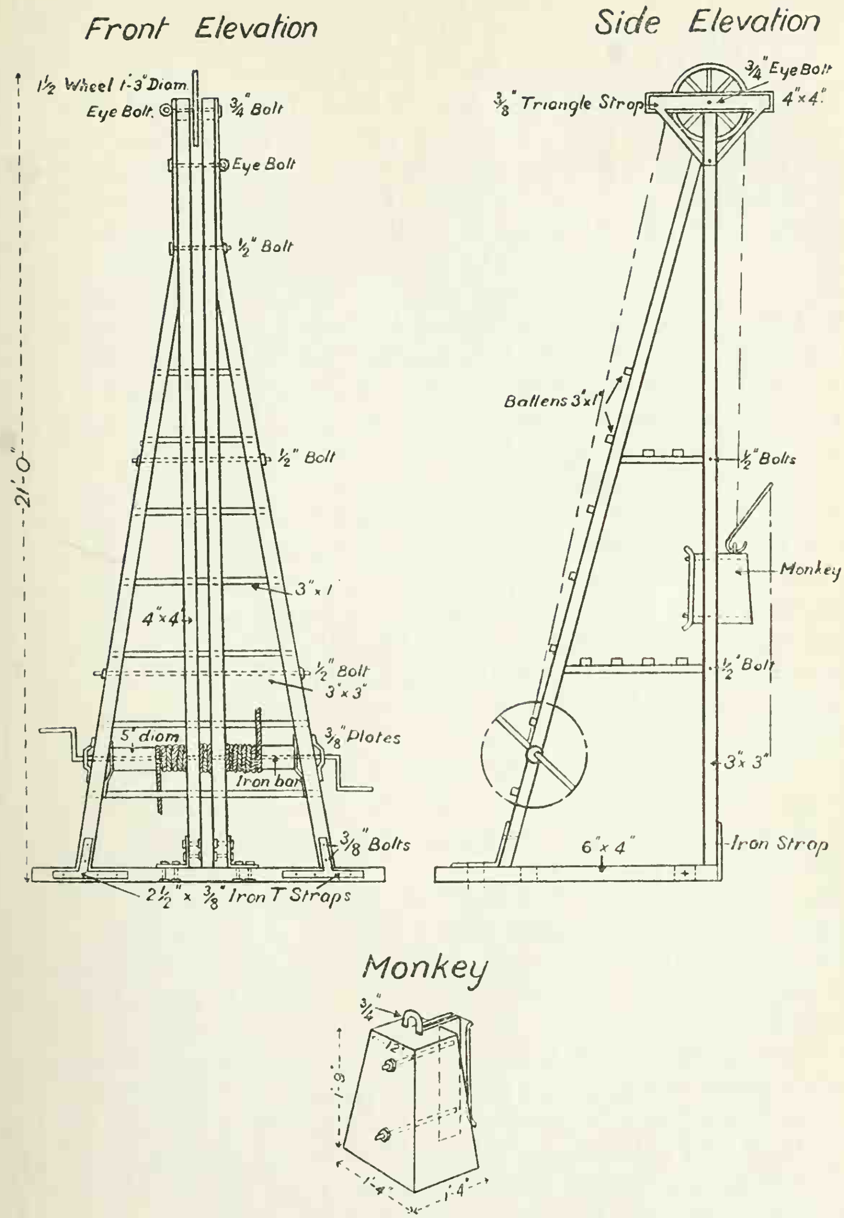

Front Elevation
Side Elevation
1½ Wheel 1'-3" Diam.
Eye Bolt.
¾" Bolt
Eye Bolt
½" Bolt
½" Bolt
3"×1
4"×4"
½" Bolt
3"×3"
5" diam
⅜" Plates
Iron bar
⅜" Bolts
2½"×⅜" Iron T Straps
21'-0"
¾" Eye Bolt
⅜" Triangle Strap
4"×4"
Battens 3"×1"
½" Bolts
Monkey
½" Bolt
3"×3"
6"×4"
Iron Strap
Monkey
¾"
12"
1'-9"
1'-4"
1'-4"

Fig. 56

may sometimes be obtained, but for most forest bridges it will be necessary to improvise a pile-driver on the site.

The essential parts are a heavy weight or monkey; a pulley, raised as high as possible directly above the head of the pile; and some form of guide to ensure that the monkey will strike the pile head squarely. For short piles the pulley may be supported by three poles lashed at their tops in the form of a 'gyn'. The monkey is raised by means of a rope which passes through the pulley, and it falls when the rope is released. The monkey may be kept squarely over the pile during its descent by three guide-ropes, attached to it on different sides and held by coolies. A better method of guiding the monkey on to the pile-head is by means of a long iron rod, one inch in diameter, which is fixed into the centre of the head of the pile and passes through a hole bored down the middle of the monkey. The monkey must be able to slide easily up and down the rod. This method has been found very successful in bridge construction at the Burma Forest School, the monkey used being a *pyinkado* stump 2 feet 9 inches long and 18 inches in diameter, bound by iron wire bands near the top and bottom. An iron rod, one inch in diameter and 14 feet long, was inserted 8 inches deep into the top of the pile, and the upper end was supported in a short bamboo tube lashed to the top of a gyn, which allowed the rod to descend with the pile and could be easily re-adjusted. The pile was kept vertical by four guide-ropes while being driven.

The use of an iron rod as a guide for the monkey in pile-driving is described and illustrated in *A Manual of Forest Engineering*, by C. G. Rogers, Vol. II. In the pile-driver there described, a single pole or derrick is used, fitted with an iron bracket and ring which supports the upper end of the rod. In practice it was found that a gyn was more convenient than a derrick, as it was easily moved from one pile to the next, and did not require either iron fittings or long guy-ropes, which are usually more difficult to obtain than gyn-poles for forest work.

For very long piles it is sometimes difficult to obtain the necessary height above the pile-head for an adequate fall of the monkey, and guides formed of two pieces of scantling may then be bolted to the pile itself, the pulley being attached to the top of the guides. The pile and guides must be held in position by guy-ropes, and difficulty is often experienced in keeping the pile quite vertical.

The pile-driving should be continued until the pile sinks less than half an inch for five or six blows of the monkey. If driving is continued after this there is danger of splitting or even breaking the

pile. In most kinds of soil the resistance to penetration will be greatly increased if the pile is left for 24 hours, so the work should not cease for the day until the pile is at the required depth. Contractors often attempt to cut off several feet from the top of the pile to avoid the cost of driving it, and to prevent this all piles should be indelibly marked with a personal hammer or iron punch at measured intervals from the point. The marks will show the exact depth the pile is in the ground and will enable the progress of the driving to be watched.

Revetments. When the bridge-posts are in position the revetment of the abutments is commenced. If round poles are used for the revetments the sapwood and bark should be removed where they are in contact with one another, and all protruding knots must be trimmed off (see plate X). The poles are placed with alternate butt ends and small ends together in order to keep the revetment horizontal. The space behind the revetment walls should be filled in with a backing of gravel or stones, if available. Undermining of the abutments is frequently caused through the revetments not being carried down deep enough below the bed of the stream.

Capsill beams. The capsill beams, on which the girders are supported, may be attached to the abutment-posts in several ways. The method of 'split capsills' shown in fig. 55 and in plate X (a), and already described, is the best for round posts. As the posts are not cut off where the capsills are attached, they can be continued upwards to form rail posts, as shown in the drawing. Heavy capsills are often placed on the tops of the abutment-posts, being kept in position by dowel pins or by iron dogs, or sometimes by means of long iron straps passing over the capsills and bolted at both ends to the posts. This method is used for trestles, as shown in fig. 59, but has the disadvantage that the posts have to be cut off at the level of the capsill beams; and, as the ends of a post usually decay first, the split-capsill method, with the posts prolonged as described above, is found to last longer and is more practical, especially for small bridges.

Ground-sills. Owing to the heavy rainfall and frequent floods in most parts of Burma and the consequent erosion of stream banks, it is usually unsafe to support the girders on a ground 'plate' or 'sill' laid on top of the bank, instead of a capsill beam bolted to posts. Exceptions to this may be made for temporary bridges and for culverts, or if the banks are of rock or are very solid and stable. The weight of the bridge usually causes the bank to break down, even if it does not get eroded, and this is a frequent cause of the premature collapse of small bridges. Bridge contractors prefer to use ground-

sills, as it incurs much less excavation and work than capsill beams, and many bridges are still built in this way, but it nearly always means a considerable increase in the span of the bridge to get a firm foundation on the banks, and as the sill is laid directly on the ground, in a position where it cannot be inspected and tarred annually, it is usually the first part of the bridge to decay.

If ground-sills are used they must be placed well behind the natural slope of the banks, and must be kept in position by strong posts sunk well into the ground on the stream side of the sills. Ground-sills should be made of the largest-sized timber available in order to give a large bearing surface on the ground and the base should be well rammed before the sill is laid. For ordinary soil the maximum load should not exceed three-quarters of a ton per square foot.

In many countries 'cribwork' abutments are used made of timber and stone, as described on page 145 for piers, but these have been found unsatisfactory in Burma owing to the heavy floods in most streams. The scarcity of stone in many forest districts is another difficulty.

Girders. The girders should be long enough to overlap the capsill beams by at least a foot at each end. Where the bridge is of more than one span, and two or more lengths of girders are necessary they should simply overlap each other on the piers, and they should be kept in position by cleats or wedges. The ends may be bolted together side by side if necessary, but should not be halved or spliced together, as beams of sufficient length can usually be obtained to allow of the overlap and a joint weakens the timbers unnecessarily and induces early decay. If it is found necessary in a special case to splice the girders, short pieces of timber should be placed across the top of the capsill beams to act as fishplates and strengthen the joints. These pieces of timber are called 'bolsters' or 'corbels'. The span between the supports must not be considered as reduced by the use of these corbels.

All sapwood should be trimmed from round girders before they are placed in position, and the top side of the girders, on which the decking will be supported, should be levelled off to form a good bearing surface so that the decking bears equally on all the girders. Only straight timber should be used for girders or a great deal of trimming will be required.

For bridle-paths, on spans up to 16 feet, two one-foot girders, spaced 3 feet 6 inches apart, are sufficient. For cart-roads the number and size of girders required is given in the statement of materials in Chapter VIII. If sawn timber is used for girders re-

member that the depth should always be greater than the breadth, as shown in the formula bd^2, already given for the strength of beams. Where large-sized timber is not available two beams are often placed one above the other to obtain greater depth for the girders, but they must be bolted and keyed together if they are to give the maximum strength.

Decking. One layer of 3-inch by 6-inch planking is sufficient for ordinary forest bridges. A second layer of planking laid longitudinally along each side of the roadway is sometimes added to take the wear of the traffic, and this extra planking can then be renewed easily when worn, without replacing the whole of the decking. This longitudinal decking is very useful for motor traffic, but in wet weather it becomes very slippery for draught animals. This is partly due to the wear being in the direction of the grain and also because the joints between the planks do not assist in giving a rough footing, as they do in the case of planking laid at right angles to the roadway. Earth should not be laid on top of the decking as it rots the wood and adds to the load on the girders.

When laying bridge decking it should not be clamped tightly together like the flooring of a bungalow, but a small gap of about $\frac{1}{4}$ inch should be left between adjoining planks. During the rains the planks expand with the moisture and, when fitted tightly together, rainwater collects on the surface of the bridge and causes the wood to rot. The decking planks should be spiked to the two centre girders only, the ends being held down by the ribbands, as this allows for expansion and contraction in their length.

Bridge railing. Ordinary bridge railing has already been dealt with in the last chapter. A stronger form of railing can be constructed, if required, by making the upper rail of 4×4-inch timber and fitting it on the tops of the intermediate posts and into mortises cut in the main posts, as shown in fig. 61. The chief objection to this type of railing is that it entails the use of iron straps to hold the rail in position on the posts, and these iron straps are frequently stolen from forest bridges. The rail-posts should be about 5 to 6 feet apart, and the top rail should be about 3 feet 3 inches above the roadway. Remember to fix the rails on the inside of the posts and not on the outer side, where they are easily pushed off the posts by animals crossing the bridge. The tops of the posts should always be pointed to throw off rainwater and to improve the appearance.

2. PIERS AND TRESTLES

Maximum unsupported span. The largest span shown in the statement of materials in the last chapter is 24 feet. Most engineering books give 18 or 20 feet as the safe maximum span between supports to be used for simple girders without struts or trusses, but where sound *pyinkado* or other similar timber is available, and girders with a minimum diameter of one foot of heartwood are used, it has been found quite safe for forest cart-road bridges to increase this span. A bridge with an unsupported span of 30 feet, built by the Forest School as an experiment, carried a load of six elephants on the bridge at the same time without any visible deflection or movement, and after six years of heavy cart-traffic, shows no signs of weakness. This bridge was built with four 14-inch diameter round girders of selected *pyinkado* timber, and was carefully constructed. For ordinary forest bridges, built by contractors, the unsupported span should not exceed 24 feet. Hardwood girders of large diameter and length are very heavy and difficult to handle without block and tackle.

Use of piers. When the length of a bridge is over 24 feet it should be divided by piers or trestles into smaller spans (see plate XIII). These piers should be erected so that they obstruct the flow of the stream as little as possible, and the row of posts forming the piers must be kept in line with the direction of the current of the stream. For ordinary streams, from 24 to 40 feet wide, a single pier is usually sufficient but where the stream bed is deep and narrow and a bridge with a total span of more than 32 feet is necessary to give sufficient waterway, it is often best to use two piers, one on each side of the stream bed, leaving one large span in the middle and a smaller span on each side. This is also the best arrangement for even a shorter bridge when crossing a deep ravine, as it leaves the widest span in the centre where the depth is greatest; the piers also get better foundations and their length is reduced. The piers should be of sufficient height to raise the centre of the bridge very slightly, say about one-sixteenth of the total span. This will give the bridge a slight camber, and also allow for any settlement that may take place after erection.

Pile piers. Even in the dry season it is usually impossible to dig deep holes in a stream bed, for bedplates or other footings for piers unless a wooden casing or 'coffer dam' is sunk to prevent the sand and water at the sides from falling in. This is a very difficult operation and the most common type of pier used for forest road-bridges consists of a single row of one-foot diameter piles with capsill

PILE PIER

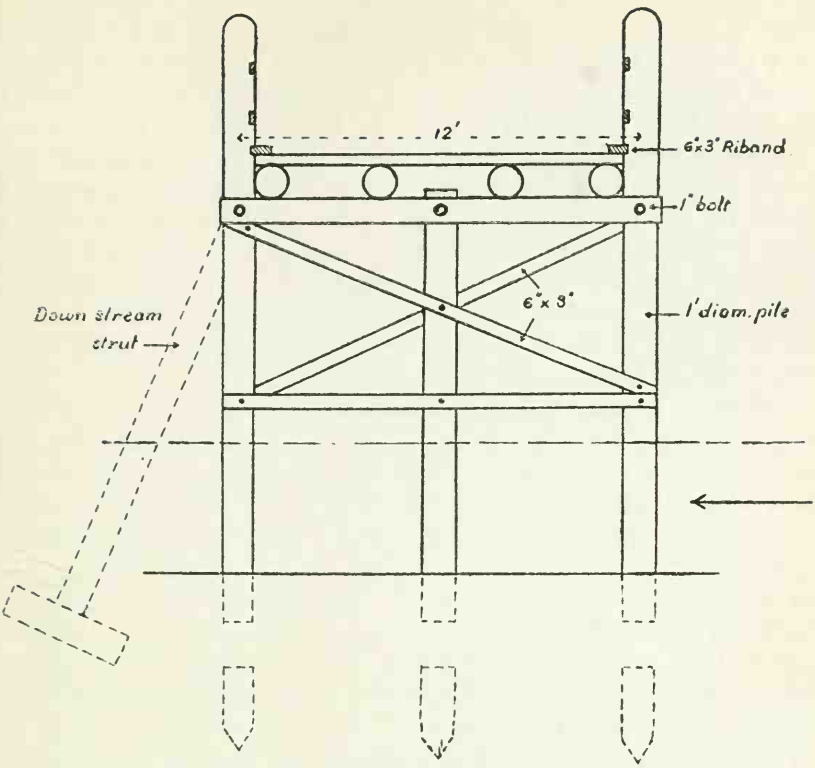


Fig. 57

CRIBWORK PIER

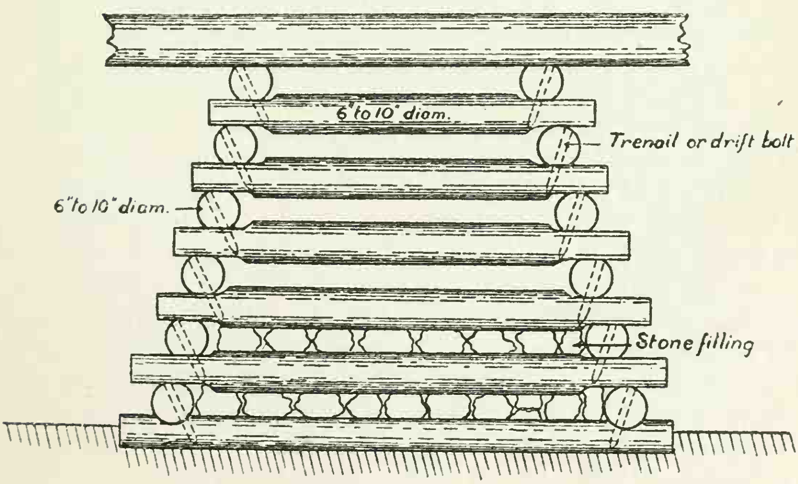


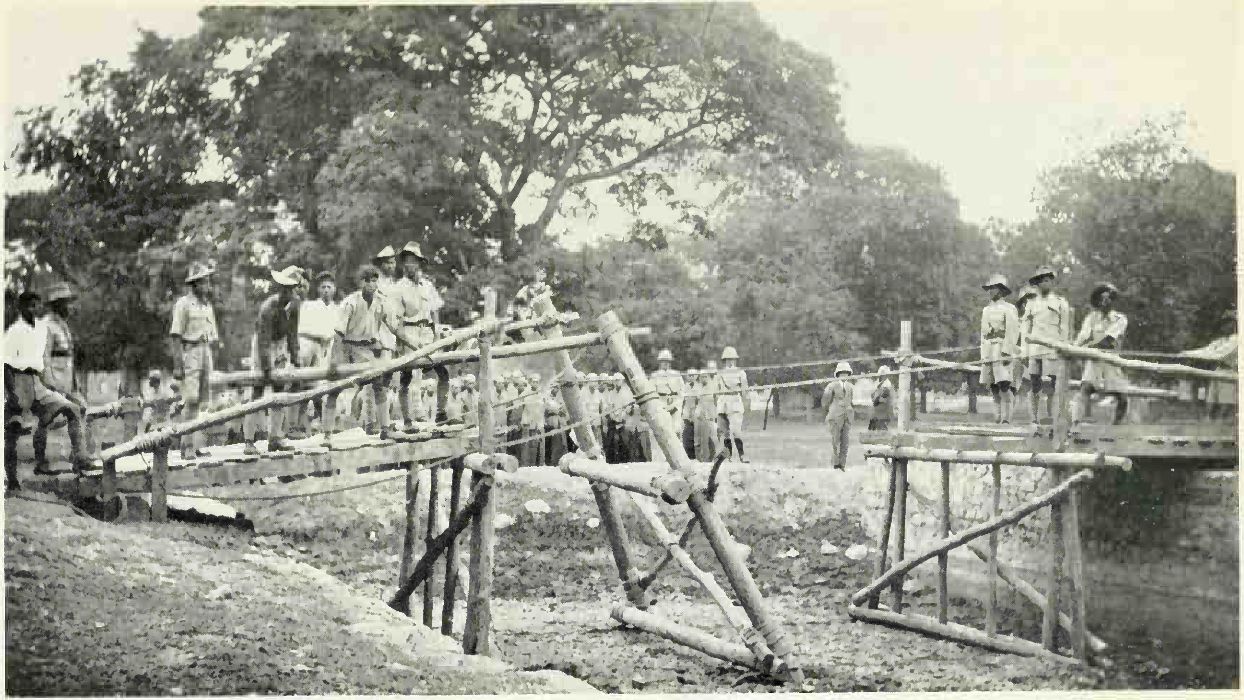
Fig. 58

beams fitted at the required height in the same way as for the abutment posts (see fig. 57). The piles should be braced by diagonal braces, and a horizontal brace called the 'ledger' is usually placed at the foot of the diagonals as shown. In the case of streams with a strong current or where heavy floods are expected an extra strut should be placed on the downstream side of the pier, as shown in outline on the left of fig. 57. The piles must be carried down to a firm foundation below the scouring point of the bed of the stream. The sand in the bed of a stream, which often appears to be very firm during the dry weather when the bridge is being erected, becomes saturated with water to a considerable depth during a flood and is then quite unstable.

Cribwork piers. For dry ravines or other places where there is no great danger from floods and floating timber, and also for temporary bridges, cribwork piers are frequently used. They may be made of rejected railway sleepers, or of round timber as shown in fig. 58. The timbers must be notched and spiked, or trenailed together, and the base of the cribwork should be sunk well into the bed of the stream and a rough tray made across the bottom. The whole crib is then filled with large stones. Cribwork piers should not be used for heights of more than 8 feet except in special circumstances, and the length of the crib should not be less than one and a half times the width of the roadway.

Trestles. Where the bed of a stream is of rock or is very stable, piers are often formed of trestles, instead of pile-driven posts. The erection of trestles is much quicker and easier than pile-driving, and they are used very frequently for temporary bridges, but a good foundation must be obtained, and they are unsuitable for use where there is a strong flow of water of more than five miles an hour. Two forms of trestles are shown in figs. 59 and 60. Fig. 59 shows a rough two-legged trestle, made of round poles, suitable for temporary work and light bridges. The poles are notched, spiked, or dogged together. Similar types of pole or 'spar' trestles may be quickly constructed for temporary purposes by lashing the spars together by rope or wire, and this is the form most commonly used for military bridges. The photograph on plate XII shows how spar trestles may be placed in position. Guide-ropes are fastened to the bottoms of the legs, and light poles are lashed to the trestle near the top. The trestle can then be launched from the banks or from the adjoining sections of the bridge. A more permanent form of trestle is shown in fig. 60, and this type is often used for cart-road bridges.

The outer or 'batter' posts of all trestles should be sloped as shown,



XII. Burma sappers and miners erecting a temporary trestle-bridge at Mandalay.

XIII. Light trestle-bridge for forest railway. This bridge is removed during the rainy season and reconstructed each year.

ROUND SPAR TRESTLE

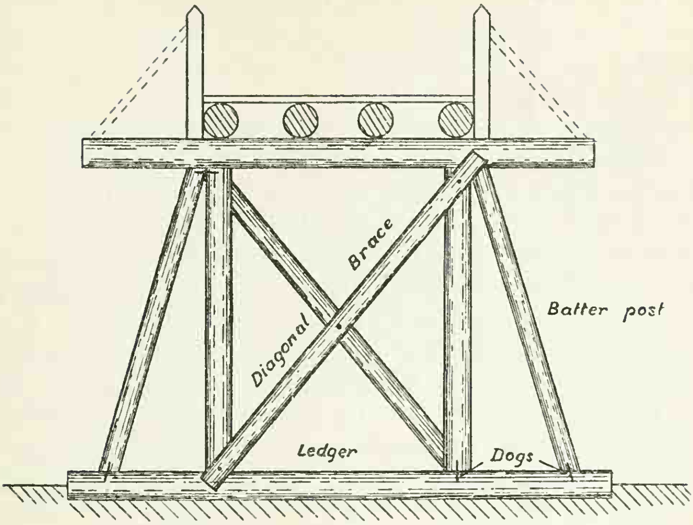


Fig. 59

FRAMED TRESTLE

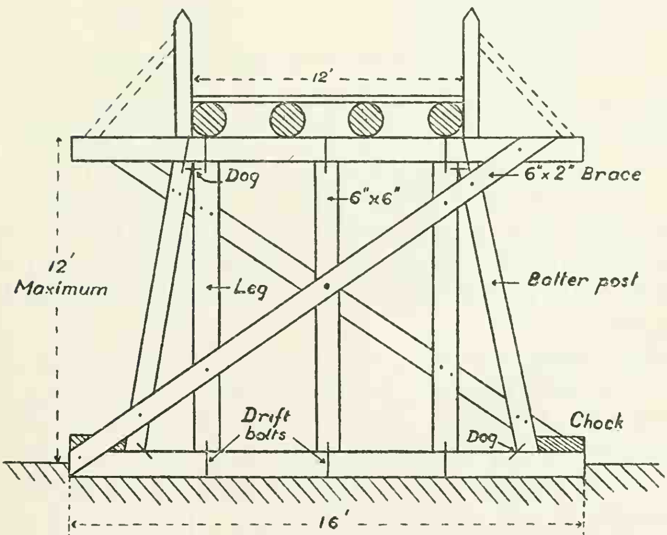


Fig. 60

at an angle of about 6 in 1. Trestles must always be braced by diagonal bracing, which is either spiked or bolted to the frame. A bottom sill or *ledger* connects the bottom of the posts and prevents the trestle from sinking into the ground. If the bed of the stream is soft, special mud-sills, formed of heavy planking, are sometimes spiked to the feet of the trestles.

For a bridge containing several spans the trestles should be braced to one another to keep them vertical, but where the stream is of considerable depth the bracing must be arranged so as to interfere with the flow of water as little as possible. For very heavy bridges sometimes two trestles braced closely together are used, forming a four-legged trestle. This gives greater stability and strength than a single trestle, but requires much more labour, and the structure is difficult to place in position and will also cause a greater obstruction.

Where streams are used for floating or rafting timber, the light wooden piers and trestles described above would get destroyed or badly damaged by the floating timber during floods. Hence trestle-bridges are sometimes removed at the beginning of the rains and replaced again in November. The forest railway trestle-bridge shown in the lower photograph on plate XIII is removed each year, and this entails considerable expense and delay. For floating streams, up to 60 feet span, this annual removal may be avoided by the use of trussed girders, as explained below, which leaves the stream clear of obstructions.

3. STRUTTED AND TRUSSED GIRDERS

For spans of more than 24 feet, whenever the depth of the gap or the nature of the stream does not permit of the erection of piers, it is necessary to strengthen the girders by struts or trusses. Struts are also used for spans of less than 24 feet where suitable timber is not available for girders of the length required; but a trussed or strutted girder bridge requires much more careful construction, and costs more, than a bridge of the same total length with simple girders or with piers.

Strutted bridges. The usual arrangement of struts for the support of timber bridges up to 45 feet span is shown in fig. 61. Two struts are placed beneath each girder as shown, and bear against a straining beam *BC*. The lower ends of the struts are supported on ledgers, which are bolted to the abutment posts, as in the drawing. The straining beams at *BC* are usually made of the same size of timber as the girders they support. The joints at *B* and *C* connecting

STRUTTED BRIDGE

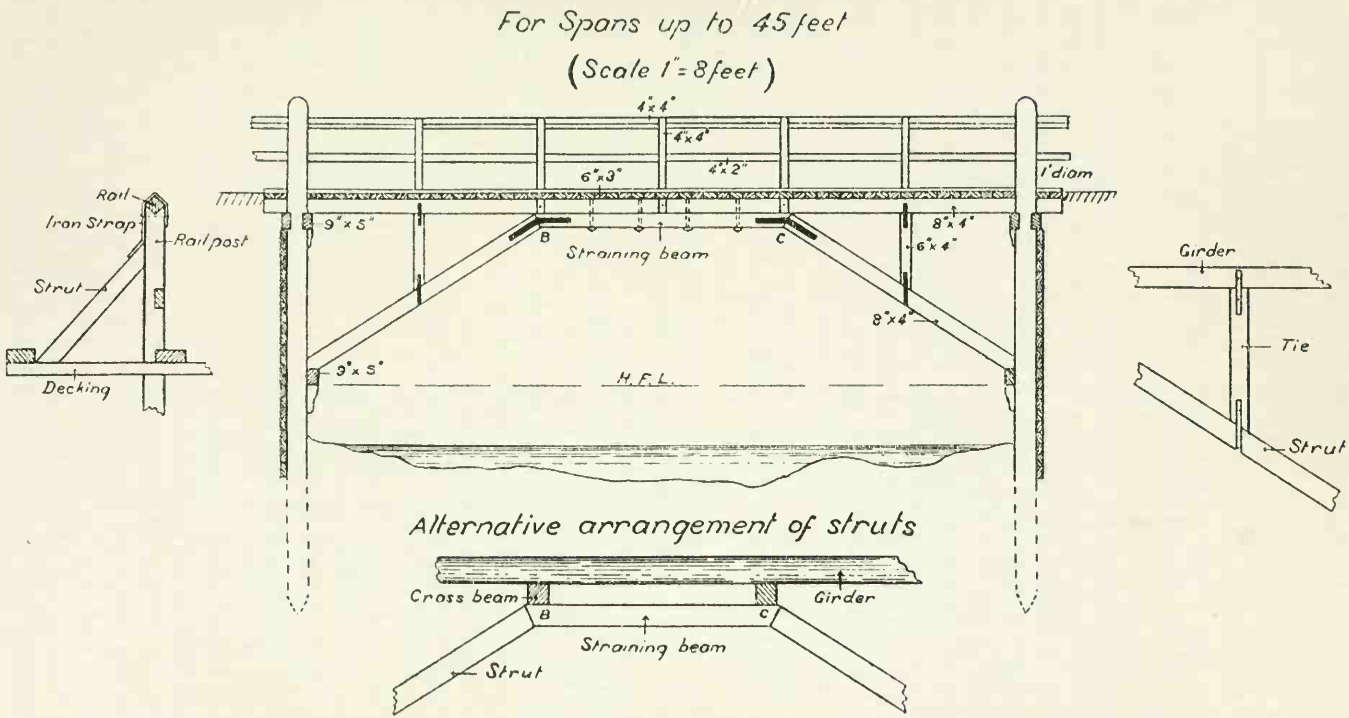


FIG. 61

the struts to the straining beams are formed so that the face of each joint is as nearly as possible at right angles to the pressure, as shown in the drawing, and this form of connexion is known as a 'mitre' joint. The length of the straining beam should be one-third of the span, and the depth from the girders to the foot of the struts should not be less than one-sixth of the span.

The girders may be formed of pairs of beams joined together over the middle of the straining beams, which are then bolted to the girders as shown. If girders are available which are long enough to reach across the whole span, then for round timber it is often convenient to use two light transoms at *B* and *C*, above the straining beams, as shown in the lower drawing in fig. 61. These transoms are the same length as the width of the bridge and join all the straining beams together. This form of connexion is essential if the struts and straining beams cannot be placed immediately under the girders, three straining beams are often used for four girders.

Trussed girders. There are many forms and designs of trussed beams and girders both of wood and of steel. Timber trusses for large bridges are expensive to construct and, owing to the great number of joints, usually decay rapidly. For permanent bridges over a certain span it is therefore more economical to use steel trusses on masonry abutments, and bridges with steel trusses have already been erected in several cases by the Forest Department in Burma and may be used more frequently in the future for some of the main extraction roads. Steel girder bridges should always be designed by qualified engineers, and where this type of bridge is erected by the Forest Department girders of standard sizes are purchased for the particular span and load required. Masonry abutments should always be provided for steel girder bridges and these abutments must also be correctly designed and their construction supervised by skilled engineers.

King-post and Queen-post trusses were sometimes used in the past for bridges as well as for roofs, but they require skilled carpenters for their construction, and unless the joints are very carefully made and are of thoroughly seasoned timber they will open up and give trouble later. Such trusses are therefore not recommended for forest bridges in tropical countries.

Trussed girders of timber combined with iron rods are often used for forest bridges. Timber is used for the struts or compression members and iron rods for the tension members. For reasons which have been given above, the depth of all girders is made as great as possible, and in the case of trussed girders the depth is usually one-seventh to one-tenth of the span.

Type design of trussed girder bridge. A suitable design for a trussed girder for a road bridge, of 60 feet span, is shown in figs. 62 to 64. This is a design which has been used for forest bridges by the Bombay Burma Trading Corporation.

The bridge consists of two braced girders, 9 feet 4 inches in depth, on which the roadway is supported. Each girder is composed of an upper and lower chord or 'boom' connected by iron tie-rods and timber struts. The upper boom is made of three rows of 8 by 3-inch planking, bolted together by $\frac{1}{2}$-inch bolts. The planks are connected end to end by butted joints strengthened as shown with $\frac{1}{4}$-inch iron fish-plates, and are arranged so as to 'break joint', as shown in the details of the joints in fig. 64. The lower boom is composed of 9×3-inch planking, and is bolted together in the same way as the upper boom. The girders are braced by timber struts, formed of three thicknesses of 8×3-inch planking bolted together at the middle through short packing pieces. The ends of the braces are notched into the booms, and are bolted to special packing pieces, which are inserted between the boom planking and are bolted to it. Details of the packing pieces are shown in fig. 64.

The booms are tied together by twenty tie-rods of wrought-iron, 10 feet long and $1\frac{1}{4}$ inches in diameter, placed in pairs, and the principal difficulty in bridges of this type is to get satisfactory bearing joints for these tie-rods. Special large cast-iron washers are generally used to distribute the strain of the rods, but these are difficult to obtain as they require special casting, and hardwood blocks of *pyinkado* may be used with iron bearing plates above, extending the full width of the boom, as shown in the drawing. These plates can be made locally of $\frac{1}{4}$ or $\frac{3}{8}$-inch iron, and for the four end joints, at *C*, of the upper booms, the plates can be easily bent to the angle required.

The cross-girders, which support the roadway, are each composed of two pieces of $14 \times 4\frac{1}{2}$-inch timber bolted together, and are made 20 feet long, so as to project on alternate sides to take wind struts of 4×8-inch timber, as shown in fig. 63.

Above the girders are the road-bearers of 8×4-inch timber, placed 2 feet 1 inch apart, and with the ends overlapping on the girders. The decking is of 6×3-inch planking held down by 6×4-inch ribbands. Packing pieces of 6×2-inch planking are placed between the decking and the ribbands.

The clear span between abutments is only 57 feet 6 inches, as the 60-foot span includes the posts of the abutments. It is important to see that the points of intersection between the centre lines of the end

TYPE PLAN OF 60-FOOT SPAN TRUSSED GIRDER BRIDGE

(Scale 1" = 8 feet)

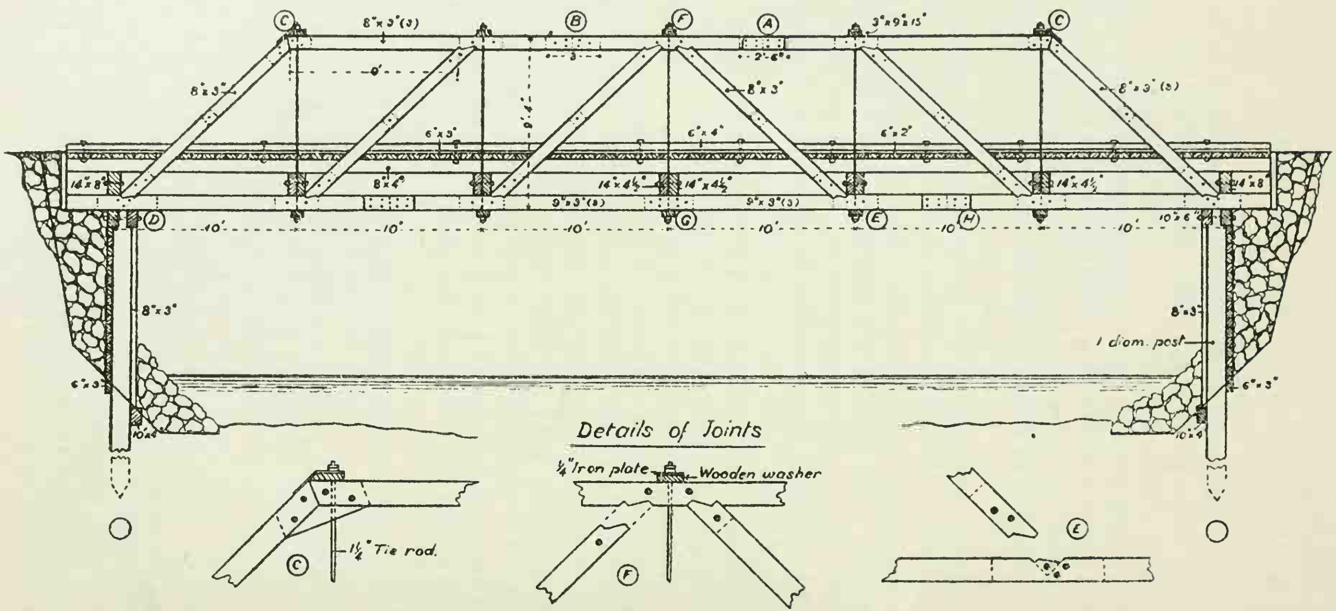


FIG. 62

TRUSSED GIRDER BRIDGE

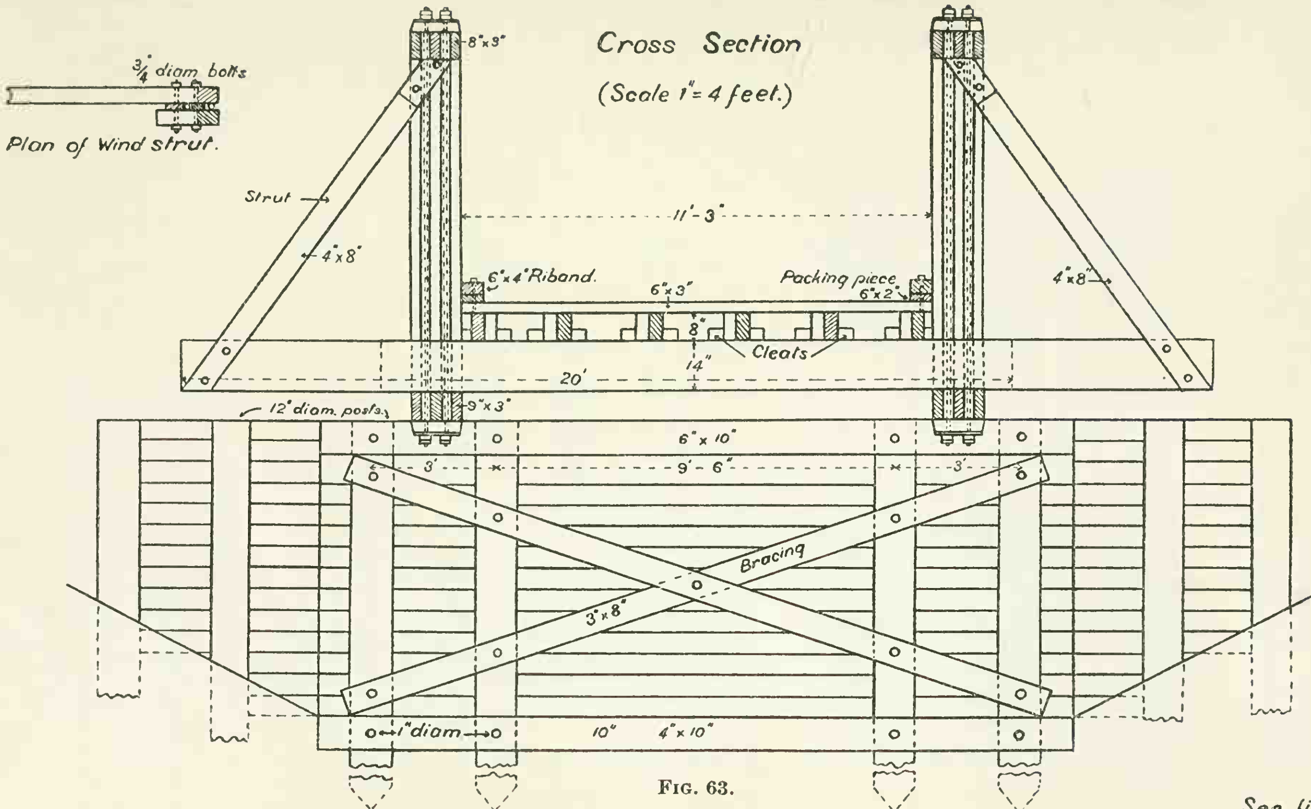


FIG. 63.

See fig. 62 & 64.

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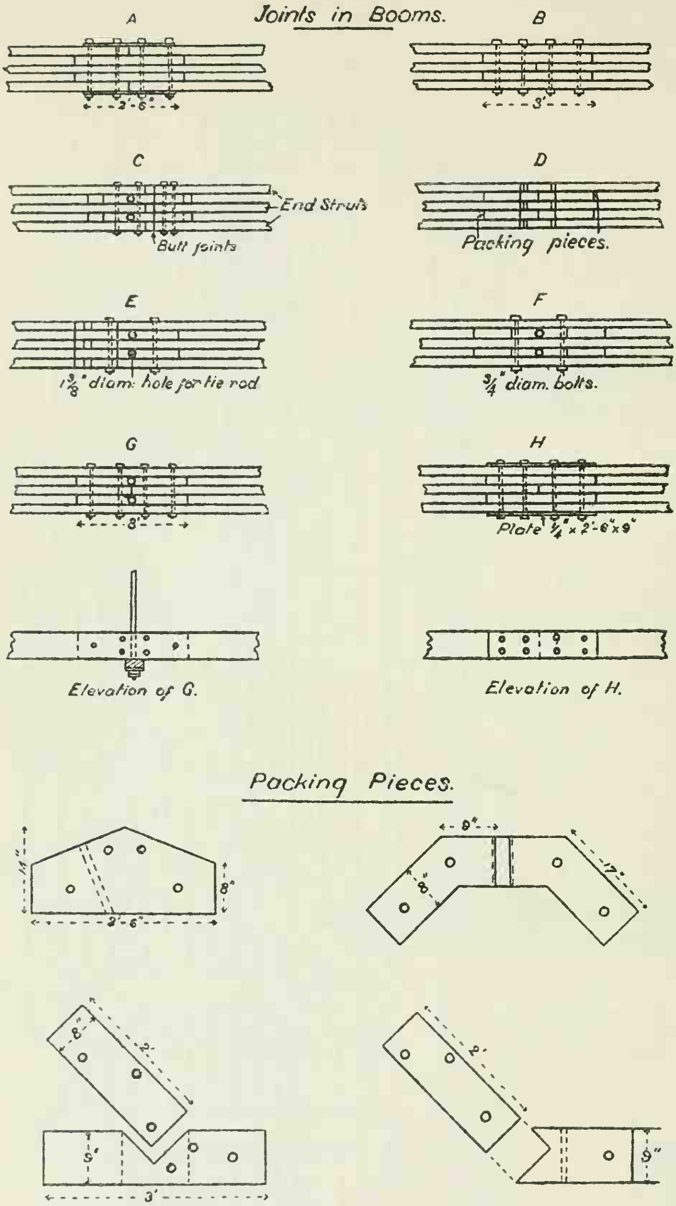
X

DETAILS OF TRUSSED GIRDER



See fig. 62 & 63

FIG. 64

struts and the centre lines of the lower booms come exactly over the middle of the main abutment posts, as in the drawing. Each abutment is supported on four 12-inch diameter piles braced as shown in fig. 63. The revetments of the abutments and wingwalls are the same as in the smaller type of bridges already described.

The erection of the bridge is simple and can be carried out by any small contractor. The bridge will nearly always be built during the dry season when there is little water in the stream and a temporary 'false work' or scaffolding of bamboos or light poles can be erected across the gap. The girders can then be built up on the scaffolding, commencing with the lower boom on each side. Packing pieces should be placed over the scaffolding so that the bridge is given a camber of about one foot while it is being bolted together. When the load is first applied the girder will always sink slightly at the middle, due to the taking up of the joints, and this will reduce the permanent camber to about 4 to 6 inches. To simplify the drawing this camber has not been shown in the elevation. The joints are simple but must be carefully made, and all the bolts and tie-rods must be tightened up evenly before the scaffolding is removed.

Cantilever bridges. These are used chiefly for foot-bridges over wide and deep ravines in hilly countries, where trestles or piers are impracticable. A cantilever bridge may consist of layers of logs built up one above the other on both banks of a ravine or stream, each layer projecting out across the stream for 5 feet to 10 feet beyond the ends of the layer below, until only a gap of 15 feet to 20 feet remains, which is then bridged in the ordinary way. The projecting logs are called 'cantilevers', and the buried ends must be well loaded with masonry or with a cribwork of timber filled with stones. The cantilevers are usually laid sloping slightly upwards towards the centre of the bridge to give a greater depth of loading on the buried ends. Transoms are placed across each layer of logs for the support of the next layer above. Owing partly to the difficulty in getting suitable stone for the abutments and to the rapid decay of the half-buried logs, this type of bridge is not at present used for forest work in Burma.

4. SUSPENSION BRIDGES

These bridges have the great advantage of requiring only wire cables and materials which are comparatively light in weight, and hence are specially suitable for bridges of large spans in places where the transport of materials is difficult and also where piers or trestles cannot be used. In forest work suspension bridges are chiefly used

for foot-bridges, as heavy suspension bridges are too costly and difficult to construct.

A suspension bridge consists of two cables, one on each side, hanging in a curve, from which the roadway is supported. The cables pass over supports on the abutments and are kept taut by being secured to anchorages fixed in the banks beyond the abutments. The cables may be of any strong flexible material, wire rope being the best as it does not stretch, but canes and even bamboo strips are also sometimes used. The supports, on which the cables are carried, are formed of timber frames similar to those shown in the photograph on plate XIV. The anchorages are generally of logs buried deeply in the ground and covered by a heap of stone boulders.

Suspension bridges are of various types and designs, and sometimes the roadway is carried directly on the cables themselves and no suspensor wires are used, but the most usual type is the sling-bridge, as in the illustration where the roadway is suspended by wire slings from the cables.

The dip of the cables at the centre of the span, below the level of the top of the piers, should be one-tenth to one-twelfth of the span. The less the dip the stiffer the bridge, but the greater the stress in the cables. A camber of one-sixtieth of the span should be allowed in the roadway, and a small allowance must be made for the stretching of the slings.

The suspension bridge shown in the photograph on plate XIV is of 200-feet span, and was built by the students of the Burma Forest School in 1914. The cables are of 4-inch wire rope, and the roadway of one-inch teak planking, 4 feet wide. The slings are of $1\frac{1}{4}$-inch wire rope, and woven wire fencing is used instead of handrailing. This bridge has now been in constant use for fourteen years, and the only repairs found necessary have been occasional replacements of planks in the roadway decking.

5. TEMPORARY BRIDGES AND CROSSINGS

Except for very large and deep streams, most watercourses in the tropics are dry or nearly dry for a large part of the year. For temporary extraction roads, which are not required during the rainy season, it is therefore unnecessary to construct expensive stream crossings.

The usual method of forming a crossing is by simply grading down the banks at each side to form earth-ramps, and making any small improvements to the bed of the stream which are found necessary. As already explained, the surface of sandy places, such as the beds of streams, can be improved by laying down grass, reeds, straw, brush-

wood, or any similar material, as this helps to prevent the wheels of carts from sinking deeply into the surface, and saves draught animals the toil of struggling through heavy sand. A good surface can be made by a layer of grass or brushwood 6 inches thick, covered by a 3 to 6-inch layer of good non-sticky earth, and a top-dressing of sand. If the stream-bed contains a flow of water throughout the year it is usually necessary first to put down a layer of logs, poles, or thick branches, laid in the direction of the stream, and then add smaller branches or straw on top. The poles or branches in the foundations allow the water to flow through and prevent the formation of a dam at the crossing.

Temporary bridges. For streams with a large flow of water it may be necessary to erect a rough temporary bridge of a similar type to the bridge shown in the frontispiece of this book. This is a typical bridge for temporary extraction roads, and was constructed by the Bombay Burma Trading Corporation. A log about 16 feet long and 8 feet in girth is laid on a naturally raised portion of the bed of the stream, and forms a transom which divides the bridge into two spans of about 20 feet. Three logs of about 4 feet in girth are placed from the banks on each side across to the central support, with their ends overlapping. On these girders is laid a decking of hand-sawn timber made of 6×3-inch planking. This decking is spiked to the middle girders, and is also held down by heavy ribbands formed of 20-foot logs about 3 feet in girth. The appearance of the bridge would be improved if the transom could be raised a little higher to make the centre level with the banks, but it answers the purpose required, and has stood heavy traffic for a whole carting season without repair. For temporary bridges of this kind the sawn timber for the decking is sometimes replaced by brushwood or poles, covered with straw or grass and about 6 inches of earth. This is cheaper but needs frequent repair, and where available the sawn timber is more satisfactory. Where a temporary bridge will not bear elephants a graded crossing must be provided for them near the bridge.

Temporary bridges for military purposes are often supported on a series of trestles constructed of round timber as shown in the photograph on plate XII. The fastenings are usually made by rope lashings. The trestles may sometimes be used as inclined struts and the bridges are then called 'single lock', or 'double lock' bridges according to the form of construction, but owing to the very temporary nature of these bridges and the high cost of the wire lashings or rope required they are not suitable for forest roads and will not be dealt with here.

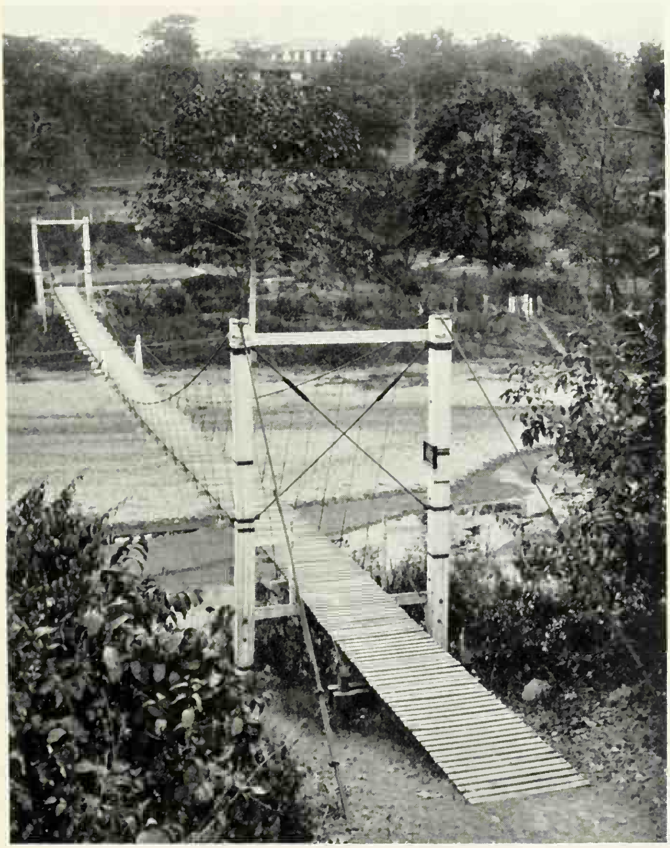
6. CULVERTS

Definition. Any covered drainage channel used to conduct water under a road, railway, or embankment may be called a culvert. A culvert may be of any size, from a 2-foot 'box' culvert to a masonry arch of 25-foot span, and the term is used in engineering to describe any form of artificial waterway which has a considerable covering of earth above it. In forest work it has become the custom to call a small wooden bridge of less than 12-foot span a 'culvert', and wooden culverts of 5-foot to 12-foot span for forest roads are usually made of the same type as the wooden bridges described in Chapter VIII. Smaller culverts may be made of large stones, round poles, sawn timber, corrugated iron, or earthenware and concrete pipes, as described below. Masonry or brickwork-arch culverts require skilled construction and are not often used in forest work.

(*a*) **Dry stone or 'slab' culverts.** Where large flat stones are available dry stone culverts can be used for spans up to 4 feet. Each layer of stones projects from 6 to 9 inches inwards from the layer below it (see fig. 66). This method is known as corbelling. The base of each side-wall must be supported independently on large-sized stones, as shown in the figure, so that the sides will not collapse if the paving of the floor of the culvert becomes eroded.

Where there is not much flow of water, and if stones flat enough for corbelling are not available, large round boulders are laid in the bottom of the channel and smaller stones placed on top, with a final topping of earth about one foot thick. This arrangement of stones is known as a 'blind drain', and is very useful for small drainage channels under forest roads.

(*b*) **Timber culverts.** Round poles can be used for culverts, as shown in fig. 67. Two hardwood posts, from 5 to 8 inches in diameter, are pointed and driven 3 feet into the ground at each end of the culvert, and from 3 to 4 feet apart, and of such a length that they project about 2 feet above the level of the finished road surface, to form guard-posts. Short intermediate posts, about 6 feet in length, are then driven 3 feet into the ground along each side of the culvert and opposite to each other, their tops being about one foot below the surface of the roadway. Revetment poles are then placed behind the posts on each side as shown in fig. 67, and also in the photograph on plate XIV. If poles over 4 inches in diameter are used for the revetments, the intermediate posts can be placed at intervals of 6 feet, but if smaller poles are used the intermediate posts must be placed closer together. Short horizontal struts are then placed between



XIV. (*a*) A simple culvert for forest roads, built of round timber and covered with brushwood.

(*b*) Wire-rope suspension bridge, of 200 feet span, for foot traffic only.

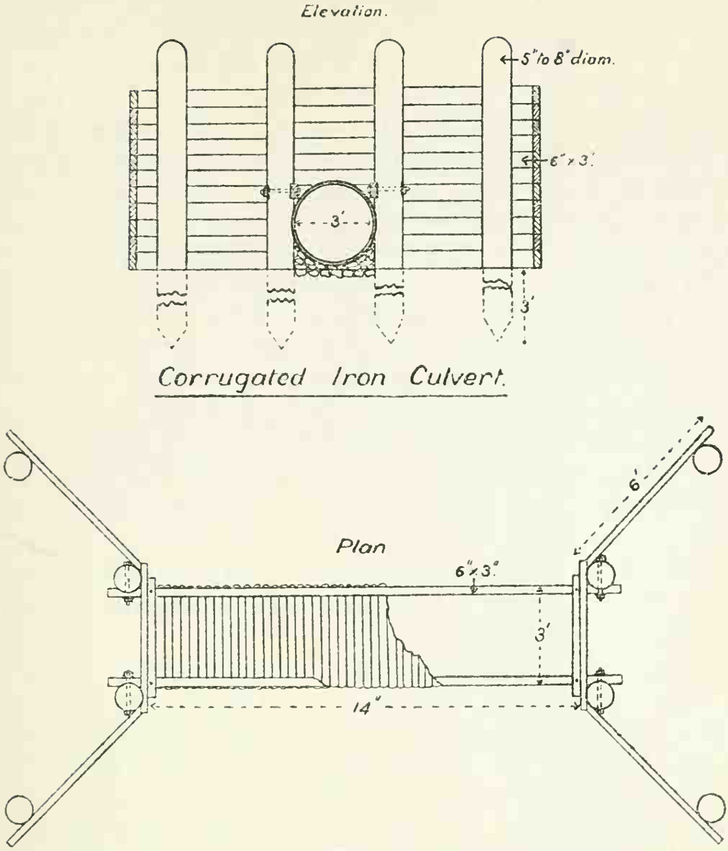


FIG. 65

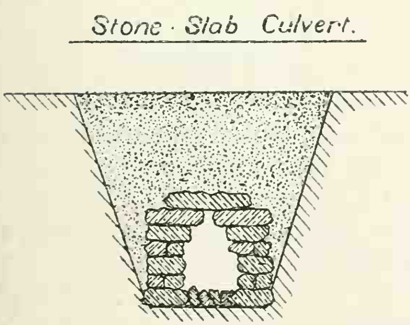


FIG. 66

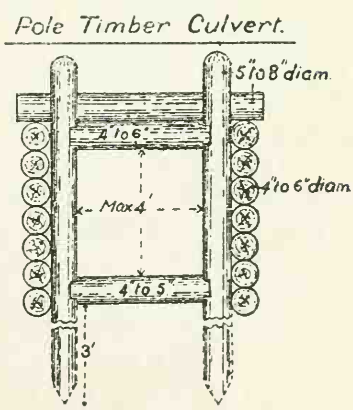


FIG. 67

each pair of posts and notched slightly into the posts as shown. They are usually also spiked in position with 6-inch spikes, but this is not neeessary if the wood is seasoned and if the notching is properly done. In the culvert shown in the photograph on plate XIV the upper strut has bccn omitted owing to the large size of the timbcr used.

The top of the culvert is then coverd in with short poles placed side by side in the direction of the roadway. The two outside poles should be notched and spiked to the end posts to assist in keeping the latter in position. A light layer of brushwood is often placed on top of the culvert before the earth covering is laid. The earth covering should be at least one foot in thickness.

The outside slabs cut from round timber when it is sawn (called *pagās* in Burma) are also often used for culverts if available near the site, the construction bcing similar to the round pole culverts.

Sawn timbcr is commonly used for culvcrts, either for the tops or to revet the sides. It may also be made into thc form of a simple 'box drain' with four sides. These culverts are more expensive than the pole culverts described above but are more quickly constructed. Where box eulvcrts are used they should be at least 18 inches square, as small culverts soon get choked up when used for forest roads and are then worse than useless.

Where they arc available, rejected railway sleepers make good strong culverts, and most of the culverts in the Burma forest school grounds are made of rejected sleepers. Their construction is similar to the round timber culvert shown in fig. 67, and is too simple to need further description.

Hollow trees may also be used for culverts, and are very durable if from *pyinkado* or tcak. These culverts tend to become choked up very easily, and should be inspected and cleared out frequently. They should be given a good longitudinal slope to keep them free from silt.

(*c*) **Corrugated iron culverts.** Corrugated iron forms a very durable culvert if properly constructed, and is very useful for culverts on main roads or in large embankments where something more durable than timber is required (sce fig. 65). Thc culverts may be made loeally of corrugated sheet-iron bent in a eircular form, with the two edges overlapping and bolted together, but it is better to purchase ready-madc corrugated iron culverts. Thcse can be obtained of any diameter and length rcquired. Thcy are usually purchased in short seetions of about 3 feet in length, and can be bolted together on the site. The bcst known makc is thc 'Armeo' culvert. The laying of a corrugatcd iron culvert is very simple. A trcnch is exca-

TYPE PLAN OF CONCRETE PIPE CULVERT

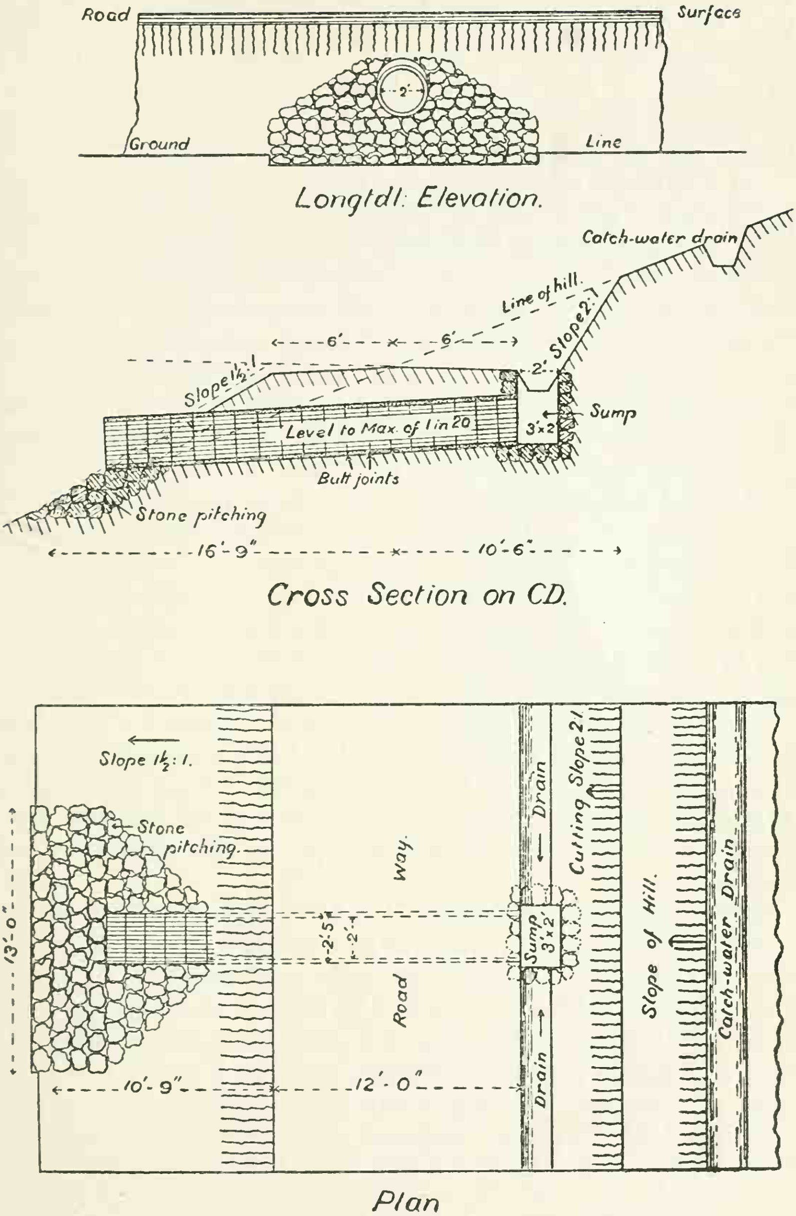


Fig. 68

vated with the base shaped in a half-round form, and slightly bigger than the diameter of the culvert. The bottom and sides must be thoroughly rammed with earth or stones before placing the culvert in position. A very durable culvert can be made by ramming concrete round the corrugated iron. Headwalls are made of 6 × 3-inch timber and are tied together as shown in fig. 65.

(*d*) **Concrete and stoneware pipes.** Earthenware or concrete pipes require great care in bedding and take considerable time to lay. The pipes should be laid on a firm even bed of rammed earth or stone, and the joints must be well filled and caulked with cement. Reinforced concrete pipes are used extensively on main roads in Burma, and a sectional drawing of a concrete pipe culvert on a hill-side road is shown in fig. 68. The pipes are usually made in short sections of one foot to facilitate transport and to prevent cracking. A common size is 2 feet inside diameter, and where more waterway is necessary two or more pipes are placed side by side.

General notes on culverts. On hillside roads a sump or catch-pit must be made at the entrance of a culvert, with its base slightly deeper than the level of the floor of the culvert. This sump will catch the silt and rubbish brought down by the water, and must be cleared out frequently. It is usually lined with wood or stone, as shown in fig. 68; and at the other end of the culvert a stone facing should be given to the bank below the culvert, as shown, to prevent erosion.

In level country the height of the culvert should be such that the top of the opening is above the flood-level of the water at the exit end, as this will greatly assist in preventing the culvert from silting up. A good longitudinal slope should be given to all culverts, but care must be taken to see that this slope is not sufficient to cause erosion.

Where there is a considerable height of embankment or earthwork above the culvert, headwalls will be necessary at each end, either in the form of dry stone revetment walls or of timber, as shown in the upper drawing of fig. 65. It will be noticed that the two headwall posts are tied together by ties of 6 × 3-inch timber, running parallel with and closely above the culverts, and bolted to the posts. Headwalls are necessary for all pipe culverts to prevent water from penetrating behind the pipes. The corrugated iron or pipe should be long enough to project at least 6 inches beyond the headwall at the down-stream end.

When the culverts have been laid, a soil covering is added and well rammed until a height of 6 inches above the correct level of the roadway is reached. This will allow for settlement. Unless headwalls

have been constructed at the ends of the culverts, the sides of the embanked earth above the culvert should be sloped at 1 in $1\frac{1}{2}$.

The Forest Department standing orders for the maintenance of bridges and culverts are as follows:

'All bridges and culverts should be frequently inspected during the rains and obstructions cleared. They must also be carefully fire protected during the hot weather. Posts and girders should be examined periodically for signs of damage or decay and urgent repairs carried out at once. A great deal of money and labour is wasted because bridges are allowed to collapse before any repairs are carried out.'

X

TRANSPORT OF TIMBER

THE actual work of extraction and transport of timber does not usually come directly within the duties of a Forest Ranger as it is nearly always carried out by timber firms and contractors. Hence a Ranger is not given special training in this work; but he should know something of the methods used, and understand the difficulties involved. Owing to the steady increase in the extraction of non-floatable hardwoods, and the fact that, in consequence, forestry operations are gradually extending into areas which are less easily accessible, the problems of extraction and transport are becoming more important year by year.

1. DRAGGING

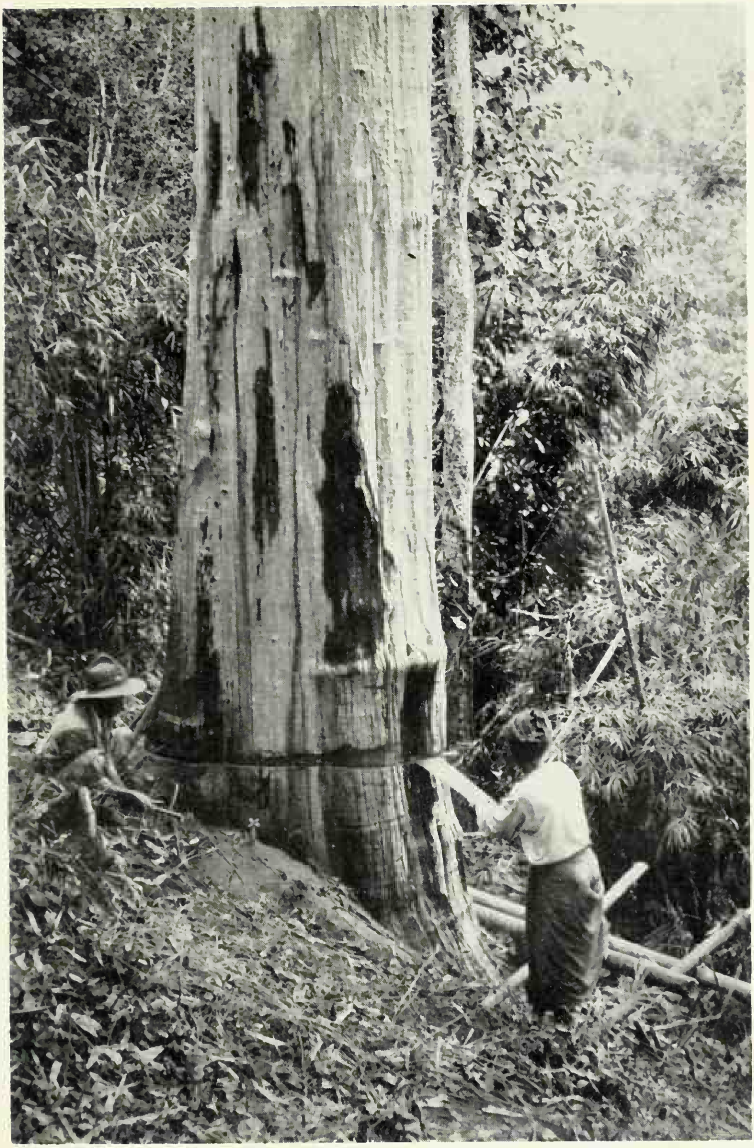
Transport of timber naturally begins at the felling site, or 'at stump', as it is usually termed. The tree is felled and logged, and no further conversion of the timber takes place at stump, except in a few places where extraction of large timber is specially difficult.

The various methods of felling and conversion of timber are dealt with in books on 'Forest Utilization'. The chief points to be observed are the prevention of all waste of timber and the avoidance of damage to the surrounding forest. The illustration on plate XV shows a tree being felled by saw alone, and where this can be carried out, it is the most economical method of felling.

The logs are usually dragged by draught animals from the felling site to the nearest point which is accessible to better and easier methods of transport; this point may be on a cart-road, a floating stream, or, sometimes, on a light railway. In Burma practically all dragging is done by elephants or buffaloes; bullocks are also sometimes used for dragging small-sized timber for short distances.

Owing to the great friction between the logs and the ground, dragging causes a heavy strain on draught animals, and halts at short intervals for rest are necessary. Hence dragging by animals cannot be considered as an efficient method of transport, but in most cases it is the only method possible.

Dragging paths. To facilitate dragging and to avoid unnecessary damage to the forests, special dragging paths are made. These paths are aligned through the felling area, and join a number of conveniently



XV. Felling teak by saw alone, to avoid waste.

situated timber dumps, or *thitpons*, to which the logs can easily be brought direct from the surrounding stumps. The distance from stump to a dragging path is made as short as possible, but varies according to the nature of the country, and whether the fellings are concentrated or widely scattered 'selection' fellings.

In most cases dragging paths require very little construction. Stumps, rocks, and other obstructions are removed, and bigger obstacles are avoided by leading the path round the side. A little extra length is always preferable to a steep gradient against the load. Short and steep slopes, if unavoidable, are often graded down by making earth-ramps. For the first part of the distance, in steep and hilly country, the paths usually follow the tops of ridges, descending into the valleys as soon as more open country is reached. As the paths get nearer to the floating stream, they frequently follow the beds of small feeder-streams. Where a floating stream is near to the felling site the logs may be dragged directly from stump down to the stream, without the intervention of a dragging path.

Short billets of wood, about 4 inches in diameter and 4 to 6 feet long, called *daleins* in Burma, are placed across dragging paths to form rollers for the logs (see photograph on plate XVI). On main dragging-paths these may be half sunk into the ground and allowed to remain there, but on smaller paths they are usually taken up by the elephant coolie after the log has passed and placed in front of it again while the elephant is resting. These rollers are specially necessary where the logs are dragged up a rising gradient or on soft ground. The softer the ground the larger the diameter of the billets used and the closer they are placed together.

Where the dragging path is carried along steep and bare hillsides it is sometimes necessary to line the outer edge of the path with poles, as in the upper photograph in plate XVI, to prevent logs from rolling down the hill. In rocky country, where the surface is very broken, long poles called *myawdons* are placed lengthwise to give a more even and better surface along the dragging path for the logs, as shown in the illustration. These 'myawdons 'are also used occasionally on short and steep grades.

If a steep grade against the load is unavoidable the logs are sometimes pulled up by a wire cable, using a simple block and tackle. The moving pulley-block is attached directly to the log and the fixed block is lashed to a tree or stump near the top of the grade. Guide-blocks lashed to adjoining trees to change the direction of the pull are often necessary in addition to the tackle blocks. When pulling a log up the grade the dragging elephant is thus able to move along

a ridge or downhill, and to use his own weight to assist him in raising the log, as shown in plates XXX and XXXI. The use of various forms of block and tackle is explained in detail in Chapter XII.

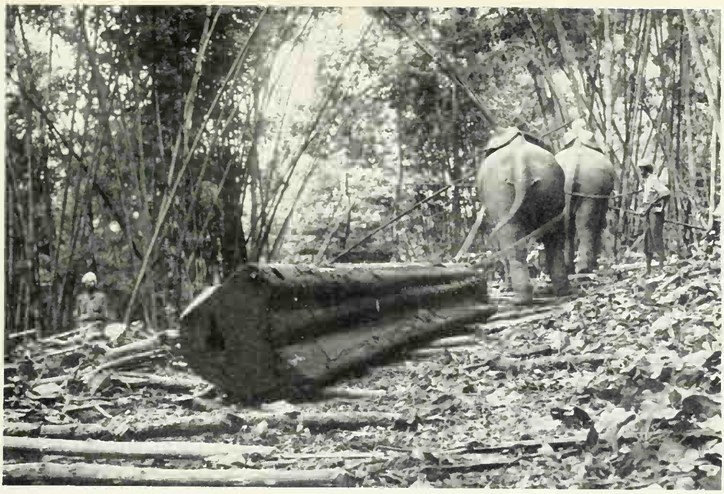
Preparation of log. There are various methods of attaching the dragging chains to the log. Where buffaloes are used a common method is by wrought-iron ring-bolts 10 inches long, with rings $4\frac{1}{2}$ inches in diameter. The bolts have a very coarse thread and are screwed into holes in the logs, which have been previously bored by an auger slightly smaller than the diameter of the bolt. These bolts are placed about one foot from the end of the log, and where two or more pairs of buffaloes are used, as in plate XVIII, additional ring-bolts are often inserted near the rear end of the log and also along the sides. Ring-bolts are seldom used for dragging with elephants, as they are very apt to break off when the animal gives a sudden jerk in starting the pull, and if a broken piece is left in the log it will of course cause great damage in the sawmill later.

Another common method of attachment used by hardwood contractors is to pass the dragging chain round the end of the log and to use a short iron drift-bolt driven into the log, to prevent the chain from slipping forwards.

The method of attachment used for teak-logs, and also frequently for other hardwoods, is to pass the chain through a drag hole, or *napah*, cut in the log in such a way that a tongue is formed about 4 inches (or one hand's-breadth) square, and 4 inches deep. This size will take the usual $\frac{3}{8}$-inch and $\frac{1}{2}$-inch dragging chains. The drag hole should be usually cut about one hand's-breadth from the end of the log, but for very big logs it is necessary to make the hole about 8 inches from the end to avoid splitting. The same drag holes are used again later when forming rafts.

Before making the drag hole in a log it should be rolled over and inspected on all sides, so that the best dragging surface can be chosen. The dragging end of the log is slightly rounded off or bevelled with an axe to prevent it from ploughing into the ground, and to enable it to slide easily on to the rollers. The amount of bevelling must not be excessive, and should be proportional to the size of the log.

In the Federated Malay States short wooden sleds or *drays* are used to raise the leading end of the log, and this avoids bevelling off the log itself, but sleds are not used in Burma to any extent. In the Delta in Lower Burma small drays are sometimes used made of hollowed-out logs in a similar form to the prow of a dug-out boat, but these are chiefly used where the dragging is done by men and in places where the ground is very soft.



XVI. (*a*) Dragging-path on ordinary ground, showing use of wooden billets or rollers.

(*b*) Dragging-path in rocky and hilly country, with heavy poles along outer edge of path.

There are several other means of attachment of the dragging chains to the log, such as by timber 'tongs', which grip the end of the log with pointed claws, but these methods are rarely used in Burma except in large sawmills.

Dragging gear. Two dragging chains are used of unequal length, and the longer chain is passed through the drag hole and then hooked or tied to the shorter chain. The longer chain, which is usually fitted with a large link at one end, is 12 to 18 feet long; and the shorter chain, which usually has a hook at the end, is 8 to 12 feet long. When pulling uphill the dragging chains should be shortened, and when going downhill they should be lengthened, to prevent injury to the feet of the elephants.

For the extraction of logs which are partly buried in sand in the beds of streams, a special long chain is used which is passed under and round the log, near the middle, in such a way that when the chain is pulled the log is rolled slowly forwards. In very soft ground or sand it is always better to roll logs than to drag them.

Where buffaloes or bullocks are used the dragging chain is attached directly to the yoke. The dragging gear used for elephants is very simple and all parts except the chains are made in the forest and from forest produce. The gear chiefly consists of a woven breastband, a small wooden saddle, and a pad, as shown in plates XVII and XXX. The breastband is woven from the fibre of the bark of the *shaw* tree (*Sterculia villosa*) or the *wetshaw* tree (*Sterculia colorata*), and is about 9 inches wide and 5 feet 9 inches to 6 feet 9 inches in length.

The saddle may be in the form of a rough saddle-tree about 2 feet long, as shown in plate XXX; or it may consist simply of two pieces of wood, 1 foot 4 inches long, hollowed out and shaped slightly to fit over the pad, and connected by two short pieces of rope as shown in plate XVII. Owing to their lightness, *yemane* (*Gmelina arborea*) or *teak* are the woods most generally used.

The pad is made of the bark fibres of *banbwe* (*Careya arborea*) or of *nabe* (*Odina wodier*), and is about 4 feet long and 3 feet broad. During the rains, bamboo-mats or pieces of raw hide are used as a cover to keep the pad dry. The dragging chains are hooked, or fastened by special links, to the loops at each end of the breast-band, and are kept at the required height by a rope sling made of *shaw* fibres passed over the saddle.

The chains and breast-band should be adjusted according to the size and build of the elephant, as the dragging power of an animal is greatly reduced if the gear does not fit. The pads should be hung off the ground when not in use, and pig's fat used liberally on the gear,

especially under the breast-band, to prevent rubbing and sores. The care of elephants and the gear used for baggage elephants is dealt with in Chapter XII.

Animal power required for dragging. Before a lessee or contractor commences extraction in a new area he has to make a rough estimate of the elephant or buffalo power likely to be required, and he has also to arrange for an even distribution of the work, so that dragging, floating, and other operations are run economically without waste of power. The work must also be so organized that no logs are left at stump during the hot weather, as they are very liable to get burnt.

The power required will depend upon the number and size of the logs to be extracted, the length and nature of the dragging paths, and the date by which the extraction must be completed.

The number of logs is estimated from the number of trees shown in the girdling or selection-felling reports, the average number of logs per tree being estimated from experience in similar previous fellings. The length of drag is obtained by measuring the distance from the nearest timber dump or *thitpon* to the floating stream or cart base, and adding an allowance to cover the dragging from stump to the *thitpon*. The length of drag to a stream capable of floating timber will not normally exceed one mile.

When the amount of timber and the dragging distances have been estimated the number of animals necessary to extract the timber in a given number of working days has still to be calculated. This will depend chiefly upon the nature of the ground. The distance an average elephant can drag an average-sized log in one working day varies from $1\frac{1}{2}$ miles in very difficult and steep country, to 4 miles in very easy country. To find the number of elephants required it is therefore necessary to multiply the total number of logs by the length of the drag in miles and divide by a factor representing the nature of the country. This factor can only be obtained by experience and after careful examination of the area.

The above method of calculation will give the number of elephants required if the work was done in one day, or the number of 'elephant days', and to find the number of animals required in order to finish by a certain date it is only necessary to divide the number of elephant days by the number of *working days* in the allotted period, after making an allowance for casualties and rest days. Elephants used for timber extraction usually work twenty days per month for nine months in the year. They are given three months' rest, during the months of March, April, and May.

XVII. (*a*) Single elephants dragging teak logs on level ground.

(*b*) Bombay Burma Corporation elephants working two abreast. This method is only used in open level country.

XVIII. Dragging heavy log with four pairs of buffaloes, one pair being attached to the rear end of the log.

The actual number of animals used in any particular area at one time is often limited by the amount of grazing and water available.

2. SLIDES AND CHUTES

Earth slides. Where it is necessary to bring down logs from a high ridge or steep hillside a sliding track, or *hto-kya*, is selected and cleared, and the logs are launched from the top and slide down endways by their own weight. The track selected is usually a natural hollow running down the hillside and should be fairly straight and free from rocks. Each log is removed as soon as it reaches the bottom of the slide, so that the following logs will not get broken or split by collision, and any rocks near the bottom must be removed before the first logs are sent down. Earth slides are also frequently made alongside floating streams where it is necessary to avoid rapids or waterfalls.

Timber slides. Various forms of timber slides are used in mountainous countries all over the world to bring down both logs and converted timber, but in moderately hilly country like Burma, timber slides are rarely used. The high cost of construction of a timber slide makes it only profitable where a large quantity of timber has to be brought down from one small area, and this only occurs where clear felling of forests is practised.

Slides for the extraction of heavy logs are usually made of round timber, placed end to end along an earth channel prepared to receive them. The sides are raised to form a trough down the middle of which the logs are allowed to slide. If the gradient is sufficiently steep the logs slide down by gravity without assistance, but they are often dragged down the slide by men or draught animals. In European countries, where slides are used for the extraction of coniferous timber, the extraction is done in the winter when there is sufficient snow to lessen the friction of the logs on the slides. When the timber has all been extracted the logs composing the track itself are sent down the slide, which is dismantled from the top downwards.

Slides of more elaborate construction are used for the extraction of sleepers, scantling, or fuel. These may be of poles or sawn timber, and are often made in the form of a triangular wooden trough and supported on trestles. The slides may be used dry or may be supplied with a continuous stream of water which is admitted by side channels and they are then known as *wet* slides. These wet slides are used chiefly for transporting sleepers and other small-sized timber where the quantity is large and the supply continuous.

Carrying. In mountainous countries the timber is commonly

converted at the felling site, and carried by men or by pack animals. This method of extraction is only used in hilly country and where it is not economical to make cart-roads. Pack mules are used for carrying converted timber and firewood in the Shan States, and pack bullocks are used for carrying firewood in several parts of Burma and India. A mule or bullock will carry an average load of 180 to 220 lb. if the load is well balanced and the country is not too rough and steep. In Kashmir where coolies are used for carrying railway sleepers and other converted timber a coolie carries an average load of about 80 lb.

3. CARTING

Wherever roads or cart tracks can be made, carting is the usual means of transport in Burma, for all timber which is too heavy to float. Heavy timbers are carted to the nearest sawmill or railway siding at a cost of about one rupee per ton per mile, plus about two rupees for loading and unloading.

Carting is also used in teak extraction in many places where the felling area is situated at a distance from a floating stream or railway, and a typical cart-base for teak is shown in plate XIX. Elephants drag the timber to the cart-base and from there it is carted to a floating stream.

Approximately twice the load can be carried on a cart than can be moved by dragging, with the same animal power, and the distance will be covered in quicker time. For very short distances, however, it may be cheaper to drag than to cart the timber, owing to the time taken in loading.

Burmese timber-carts. Practically all the carting in Burma is done on simple two-wheeled carts. Two of these carts are occasionally used together for very large logs, but four-wheeled carts or timber waggons are very rarely used, their heavy weight making them too unwieldy. The actual size of the cart varies in different parts of Burma, and also according to the load to be carried, but the type of cart shown in plate XX is used generally all over the Province.

A typical Burma cart consists of a wooden axle, a pair of wheels and a block of wood, or *zindon*, placed over the axle to support the load. The whole of the cart can be made in the forests. The wheels, which are the only parts of the cart containing iron, are usually made by skilled labour in blacksmiths' huts situated as near to the site of the work as possible, to enable repairs to be carried out without delay where required. Large contractors and lessees usually get their cart-wheels made and issue them as required to the cartmen. They also

XIX. A cart base. The logs have been dragged to this point by elephants and placed into position ready for carting.

keep the wheels in repair, but the cartmen make and repair the remainder of the cart themselves.

The Bombay Burma Trading Corporation makes wheels with rims varying in width from $2\frac{1}{2}$ to 6 inches. Wheels with 3 and 4-inch rims are used for ordinary carting, and 6-inch rims are used only for large logs of over 3 tons. The smaller $2\frac{1}{2}$-inch rims are used for small logs and bullock carts and also for 'leader' carts when using several pairs of buffaloes, as shown in the frontispiece. For wheels of $2\frac{1}{2}$ to 4-inch rims, 7 felloes and 7 spokes are used; and 6 felloes and 12 spokes are used for rims of 5 to 6 inches.

The hub is usually made of *padauk* (*Pterocarpus macrocarpus*) and the remainder of the wheel is made of teak. The axle is made of *sha* (*Acacia catechu*) or *pyinkado*, and is 7 feet long. This gives a wheel base of 5 feet. The shafts are formed of two rough poles about 5 inches in diameter, made of any tough elastic wood such as *sha* (*Acacia catechu*) or *panga* (*Terminalia chebula*). The length is from 12 to 15 feet, of which 10 to 13 feet are in front of the axle of the wheels and 2 feet project behind. The yoke is 5 to 7 feet in length, and is made of *teak*, *yemane* (*Gmelina arborea*) or *panga* (*Terminalia chebula*). The block of wood which forms the frame of the cart and is placed above the axle is 4 feet long, 6 inches wide, and about 18 inches deep, and is usually made of *pyinkado*.

One pair of buffaloes can cart logs up to one ton in weight, on average roads with easy gradients; but a log weighing from 2 to 3 tons will require three to four pairs of buffaloes yoked in span. The average load for a cart drawn by one pair of bullocks, on earth-roads, is 1,400 lb. up to 7 miles, and 1,000 lb. for long distances.

Heavy timber-carts or 'gindeiks'. These are special carts used for hauling heavy timber where the country is too difficult for ordinary carts. They are intended chiefly for elephants but are also occasionally drawn by buffaloes. *Gindeiks* do not require proper cart-roads and are able to stand rough usage. They lighten the labour of elephants, especially for very heavy timber, and can be made in the forests as no ironwork is used.

The sketch in fig. 69 shows the construction of a typical *gindeik*. The wheels are solid sections of *thabye* (*Eugenia jambolana*), *panga* (*Terminalia chebula*), or *yemane* (*Gmelina arborea*). They have a 9-inch tread, and are 15 inches broad at the centre of the axle-box, which is 7 inches in diameter. The axle is 6 inches in diameter, and usually of *panga* or *gyo* (*Schleichera trijuga*), and can be made of any length to suit the size of the timber.

The shafts are usually 9 feet from the centre of the axle to the

end of the pole, and are bound together by a short piece of chain or raw hide, as shown in the drawing. The dragging chain is fastened round the joint between the two shaft-poles. In America a similar type of cart is used for horses and is called a 'bummer'.

Big-wheeled carts. The only other timber-carts in common use in Burma are the 'big-wheel' carts of various sizes, used chiefly in timber depots and sawmills to move logs for short distances and on level ground. The log is slung under the axle, and this saves considerable time in loading. These 'big-wheel' or 'high-wheel' carts are used extensively in America and other countries, and have been tried from time to time by timber lessees for jungle work in Burma, but on uneven ground the log swings badly, and the large amount of iron in the construction makes the cart difficult to repair in the forests when broken. Another disadvantage is the heavy weight of the carts when empty, as the return journey after unloading has often to be made up steep gradients, and a heavy cart gives no rest to the animals.

4. METHODS OF LOADING

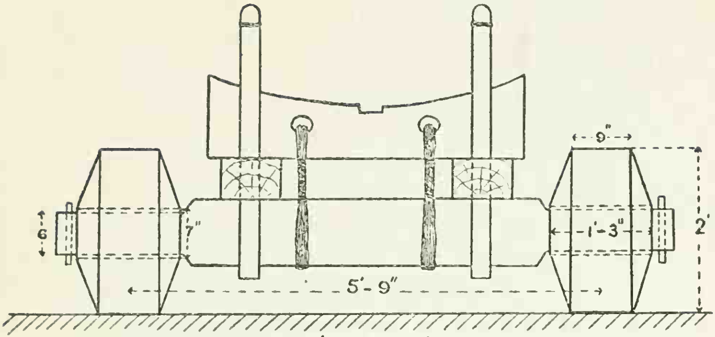
Loading by animal power. Where carting is used in teak extraction as a link between the dragging paths and a floating stream the logs are usually placed in position by elephants, ready for loading on to the carts, as in plate XIX, which shows a Bombay Burma Trading Corporation cart-base with logs arranged for loading. The logs are placed in rows with one end raised over a large cross-log or *ohn-don*, as shown, so that they are supported near the middle and almost at their point of balance. Where elephants are not available the logs may be dragged over the end of the cross-log by buffaloes, with the assistance of inclined poles. A cart is then backed under the raised end of the log, as shown in plate XX, and the log is levered slowly forward with iron crowbars until its point of balance is transferred from the cross-log to the axle of the cart, as shown in the second photo. The log is then in position on the cart. A chain sling is passed over the middle of the log and attached to the cart; the balancing of the log being afterwards controlled by the driver, who rides on the log near the middle and keeps it at such an angle that the lower end of the log is just clear of the ground on level roads, and acts as a brake by resting on the ground when descending steep gradients.

Another common method of loading is by using the shafts of the cart as levers to raise the end of the log to the necessary height. The cart is tilted until the projecting rear ends of the shafts are on either side of the small end of the log. A short chain is passed under the

XX. (*a*) Loading timber-cart by levering log forward with iron crowbars.
(*b*) Log balanced in position on cart, ready for hauling to the nearest floating stream.

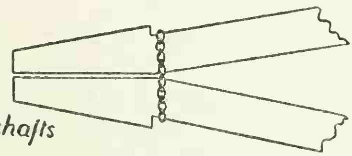
HEAVY TIMBER-CART

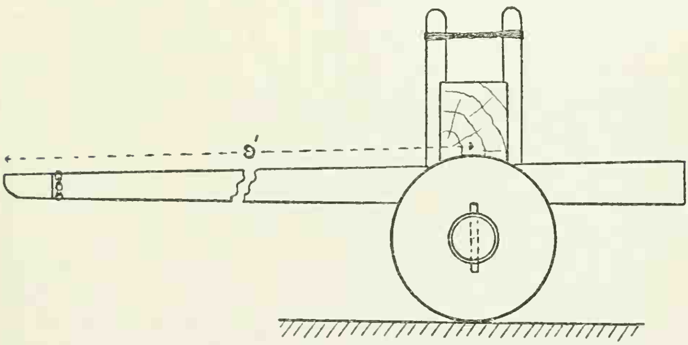
(Scale 1" = 2 feet.)



End Elevation

Plan of junction of shafts





Side Elevation

Fig. 69

log and attached to the ends of the shafts, and blocks are put under the wheels. The yoke of the cart is then pulled down by five or six men until it reaches the ground. This slowly raises the log, and packing pieces or props are placed beneath it. The yoke is then raised and the cart is pushed farther under the log. This process is repeated until the end of the log is raised to the required height, and the cart is then backed under the log and loaded as in the first method. For heavy logs two extra poles are sometimes used to serve as levers. These poles are tied at one end to the cart-shafts and placed over the frame of the cart. They project beyond the rear ends of the shafts, which are tilted up and used as before.

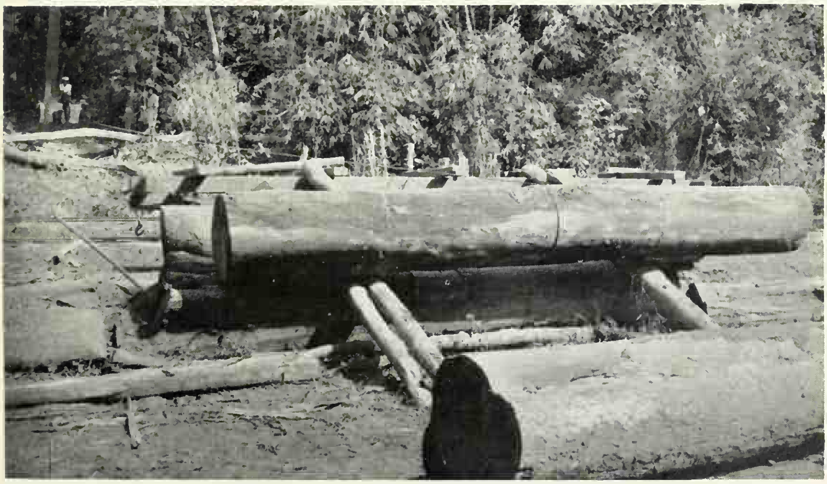
In some districts the cart is tilted forwards until the ends of the shafts rest on the ground, and short rollers are placed at intervals across the shafts. Buffaloes or bullocks are then harnessed to the end of the log, and either drag or push it forward over the rollers on to the cart, and the final balance is adjusted by crowbars. Water is often poured over the log to make it slide more easily over the frame of the cart.

Loading is sometimes facilitated by digging two short trenches for the wheels so that the cart can be backed underneath the log, the end of which is slightly raised. The log is then levered or dragged into position on the cart as before. The outer ends of the trenches are given a gradual slope so that the cart can be easily extracted.

Mechanical loading. Where there are many logs to be loaded, as at a cart-base or other centre, a rough wooden gantry is sometimes erected, consisting of two poles 8 to 12 feet apart, with a cross-bar attached. The logs are raised by a simple block and tackle, or a differential-gear tackle attached to the cross-bar. For simpler gantries the cross-bar is laid loosely over two forked poles and rotated by long handles in a similar manner to winding a winch, the lifting chain being wrapped round the cross-bar, but this method is not common.

Monkey-jacks are also frequently used for loading carts. Loading by means of a derrick and skidder is shown on plate XXI (a).

Parbuckling. This is a method used more frequently for loading wagons and railway trucks than for loading carts. Plate XXI (b) shows a large *pyinkado* log being loaded by parbuckling, on to a light railway wagon. The logs are first dragged into position parallel with the wagon and a short ramp made of leaning poles is placed against the side of the wagon as shown. A wire rope is attached at one end to a firm anchorage near the ground; in the case illustrated it is attached to the rail on which the wagon is resting. The other end is passed over the wagon and under the middle of the log, and then back again over the



XXI. (*a*) Loading heavy timber with a high-line skidder.

(*b*) Parbuckling logs on to railway wagon with a monkey winch, which can be seen near the left-hand top corner.

XXII. High-line skidding of heavy *pyinkado* timber in Lower Burma.

log and the wagon. The rope is then connected to a monkey winch which is attached to an anchorage tree about 15 yards from the wagon, as shown. As the rope is pulled the log rolls up the ramp and on to the wagon. Animal power may be substituted for the monkey winch to haul the wire rope, and in loading big logs two ropes are frequently used, placed about 6 to 8 feet apart.

Cranes, steam loaders, and other mechanical methods of loading are used in timber depots and on railways, but are not often used in forest work.

5. MECHANICAL METHODS OF EXTRACTION

Various methods of extraction by mechanical means, such as by skidders, wire ropeways, and motor tractors, are used all over the world, but in Burma, although many of these methods have been tried from time to time, they have proved unsuccessful except in a few special cases. One of the chief reasons for the failure of mechanical methods in Burma is the small amount of marketable timber per acre. Expensive machines such as skidders, which may cost from Rs. 15,000 to Rs. 1,00,000, can only be profitably used where they can be worked continuously at their full capacity, and this can only be done where a large amount of timber is to be extracted from a comparatively small area, as in the case of most American forests where clear felling is the general rule and practically all tree species have a marketable value. Another important reason against the adoption of mechanical methods is that elephants and buffaloes are available. The maintenance of these animals is comparatively cheap, and they are particularly suited to the special conditions of timber extraction in the tropics. There are also other reasons, such as the lack of skilled labour and the shortage of roads and forest railways suitable for the transport of heavy machinery, and it appears unlikely that mechanical methods will replace the elephant and buffalo in Burma and similar countries for very many years.

There are, however, a few skidders and tractors at present being used in Burma, and when the areas become exploitable which are now being regenerated with pure crops of marketable species, these machines may be used more extensively.

Skidders. 'Skidding' is the American term for dragging, and machines for dragging or hauling logs by means of wire ropes are called 'skidders'. A skidder, or steam winch, consists of a boiler, an engine, and two hauling drums, assembled together on a steel or wooden frame so that the whole machine can be easily moved from place to place. In the simplest form of skidding, called ground

skidding, a rope is attached to one end to the hauling drum and the other end is taken out into the forest and attached to the log to be hauled. The drum is revolved by steam power and the log is hauled along the ground until it reaches the skidder. The great disadvantage of this method is that the logs jam against roots, stumps, and other obstructions, and rubbish and earth collect in front of the log and increase the pull on the rope. To get over this difficulty the hauling rope may be passed over a snatch-block, raised on a tall derrick, or attached to the top of a tree near the skidder. This raises the leading end of the log but is effective only for a comparatively short distance. This method is known as 'High Lead' skidding.

A better arrangement for hauling logs over broken country is by the use of a main cable line raised off the ground for the whole length of the haul. A fixed wire rope or cable is suspended from convenient trees along the direction of the haul at a height varying from 30 to 60 feet, and the hauling rope is attached to a 'carrier' which runs along this fixed cable. The carrier and hauling rope are taken out to the end of the line by means of an *out-haul* rope which is attached to a second drum on the steam winch or skidder. The hauling or skidding rope passes over a pulley in the carrier and is attached directly to the log. The log is then hauled along by this rope with one end of the log raised and the other end dragging lightly over the ground. The photographs shown on plate XXII were taken at Swa, in Toungoo Division, Lower Burma, where the skidder was used to transport logs for a distance of about half a mile, from the end of a 2-foot gauge feeder railway to the main logging railway leading directly to the mill. Two difficult obstacles had to be crossed, a steep ridge and a wide stream, which prevented ordinary methods of transport from being used. The 2-foot gauge railway was continued up one side of the ridge to the top, and the skidder was first used to haul the loaded trucks to the top of the ridge. Here the logs were unloaded and attached one by one to the skidder rope, which then hauled them down the other side of the ridge, across the stream, and loaded them directly on to the trucks on the main logging railway, as shown. Other skidders have been used from time to time in timber depots in different parts of Burma, but they have not generally proved a financial success. It was found that about 50 logs a day could be hauled an average distance of 1,000 feet by a small skidder.

Aerial ropeways. Overhead skidding, as described above, is a form of aerial ropeway, but the term 'ropeway' is only used where the log is completely raised off the ground and carried in the air by a special carrier. Aerial ropeways are chiefly used in mountainous

countries to carry logs down very steep hillsides and over deep valleys and other obstacles. The logs usually descend by gravity. The weight of the log in descending is used to convey other empty carriers to the top ready for loading.

Tractors. Tractors in general require hard and fairly level roads, and owing partly to the shortage of metalled roads, and partly to the lack of skilled mechanics and the consequent difficulty in getting repairs done out in the forests, the use of steam or motor tractors for forest work in the tropics is very limited. Another reason that they are not more widely used in wet tropical countries is because during the rainy season, which lasts from four to five months, the tractors can rarely be used and the capital invested is lying idle. The cost of maintenance is also very high compared with animal power.

A few motor tractors are now being used in Burma for the extraction of non-floatable hardwood timbers, and those with 'caterpillar' treads which enable them to travel over soft or rough ground are found to be the most suitable. Caterpillar tractors have also been used for the extraction of teak in specially difficult country where other means of transport could not be used, but no form of tractor has yet been invented which can compete with the elephant for ordinary timber extraction in broken, hilly country.

Forest railways. The use of light railways in the forests for timber extraction and transport is very common both in Europe and America, but is comparatively rare in Burma because teak, which is the chief timber extracted, is a floatable timber. In most localities where teak is grown there are good floating streams available, and above the floating streams the country is usually too hilly or broken to make the construction of a railway a profitable undertaking. Another important reason against the use of railways is the widely scattered fellings under the selection system and even where clear fellings are practised the yield of marketable timber per acre is often too small to justify the cost of a railway. Where big sawmills are established, however, a light railway often becomes necessary to keep the mill supplied.

Forest railways can be used the whole year round and timber can be extracted quickly at any time over long distances. This enables the maintenance of a steady supply of timber to large sawmills or depots, and saves the storage of large reserves of round timber. Storage of logs entails loss in the case of most timbers, as the advantages gained by the seasoning or drying is more than balanced by the tendency to rot and decay, and many timbers are more easily sawn when green.

Compared with road transport, timber extraction by railway can be

better controlled, as it is not subject to the uncertainties of cart traffic. Again, in the case of water transport a large percentage of logs are damaged or lost, and this loss is saved by the use of railways.

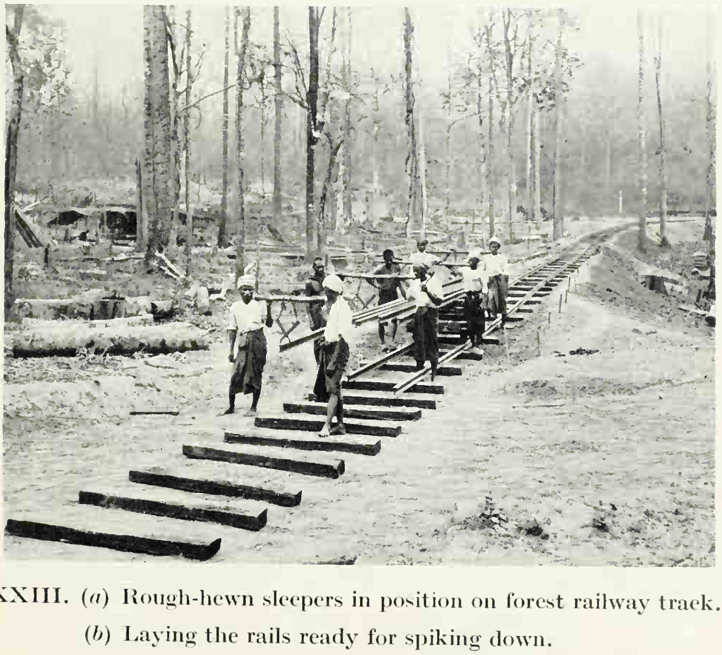
Light railway tracks are usually cheaper to construct than good metalled roads, but the initial cost of a railway with its rolling stock is very high, and this cost must be distributed over a large quantity of timber to make the construction profitable. The cost of working and maintenance of a railway is also high. Railway construction in the type of hilly country where most of the valuable forests in Burma are situated is very costly, as numerous bridges and deep cuttings are necessary, and the chief use of light railways is to cross the more open country between the forests and the main railway or sawmill.

Plates XXIII and XXIV show the construction of a light forest railway. The rails are spiked directly to the sleepers, which are roughly hewn baulks of timber obtained from the local forests. The methods and details of the construction are shown in the photographs. Temporary 'spur' lines are generally used to connect the main logging railway with different parts of the forest, and these are often constructed in the beds of streams. These spur lines are lightly constructed to enable them to be easily removed when required.

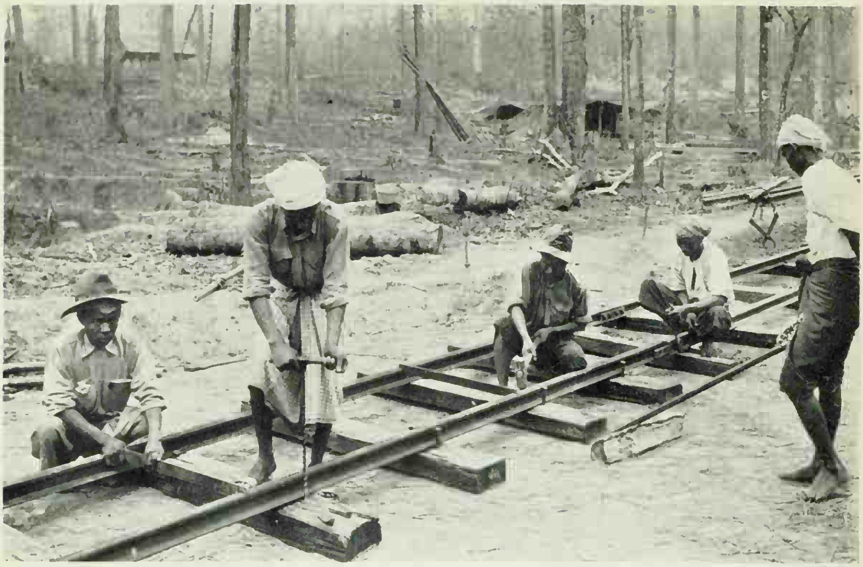
The alignment of a light railway is similar to that of a road but it is more important to keep the line as straight as possible, and the shortest line is taken even where this involves more excavation or embankment. Where curves are unavoidable they are carefully laid out with a minimum radius according to the gauge of the track and the kind of wagons used. The ruling gradient will also depend on the kind of engines and rolling stock used and may vary from 1 in 25 to 1 in 50. If small wheels are used the gradient can be made steeper than with large wheels, but if very steep gradients are used an elaborate system of brakes is necessary and this adds greatly to the cost of the wagons. There are many types of rolling stock used, but the consideration of the various kinds of engines and railway wagons is too large a subject to be dealt with here.

The gauge of the railway track may be from 2 feet to one metre. The narrower gauge is slightly cheaper in first cost, but the maintenance costs are almost as high as the metre gauge lines, and the carrying capacity is much less. The metre gauge is more economical than the narrower gauge in places where a large amount of timber can be reached without moving the track. Quick methods of loading are essential for a railway, and mechanical means, such as loading cranes, are usually installed at main loading points.

In many countries 'forest tramways' are used on which the wagons



XXIII. (*a*) Rough-hewn sleepers in position on forest railway track.
(*b*) Laying the rails ready for spiking down.



XXIV. (*a*) Spiking down the rails and bolting the fishplates.
(*b*) Bending the rails to the required curve.

are hauled or pushed by men or draught animals, and an animal can haul six times as much on a tramway as on a cart-road. The first attempt to make use of tramways by the Forest Department for the working of teak in Burma was in 1912, in Zigon Division, and for several years a tramway was worked with a fair amount of success. The experiment afterwards proved to be a failure for teak extraction, and tramways have not been used by the Forest Department since. Pole tramways are used in Australia and in America, in which round poles are substituted for steel rails, but so far this type of tramway is not in general use in tropical countries; this may be due to the rapid deterioration of the poles in contact with the ground, and the presence of white ants.

6. TRANSPORT BY WATER

Water is the cheapest method of transport of timber, and where rivers are numerous, as in Burma and Siam, practically all teak and floatable timber is extracted by this method. The timber may be transported by floating in single logs, by rafting, or sometimes by the aid of boats.

Launching and floating. Floating is used only in streams which are not fit for rafting, and as soon as a suitable stream is reached the logs are made up into rafts. Logs which are dragged or carted to a floating stream during the dry season are usually launched at once into the stream bed, but if the total number of logs launched is more than the stream will carry there is a danger of jams. Logs dragged during the rains, and all 'green' teak logs, are piled or *poned* on the banks at selected sites, which are convenient for measuring, fire protection, and launching. The launching of teak logs is shown in plate XXVI. The floating streams are patrolled continually, during the rainy season, with elephants. Logs left on the banks by the last flood are again launched, and logs lying on high shelves or in shallow places are also rolled or *aunged* into the main channel. This work of *aunging* is best done while the stream is actually rising and in flood. Any timber jams which have formed are broken up as quickly as possible, and large obstructions, such as trees which have fallen into the stream and are blocking the channel, are removed.

The floating depends upon the sudden rush of water during a 'rise', or spate, carrying down the logs to deeper streams. Small spates in floating streams often cause more harm than good, as they only serve to bunch the logs together, owing to the small logs floating and the larger ones remaining stationary. For this reason a small clear channel is often left in the middle of the stream, which allows a small

flood to come down without moving the timber. Many streams are too shallow, even when in spate, to float the logs, which have then to be partly floated and partly dragged by elephants down to deeper streams (see plate XXVI (b)).

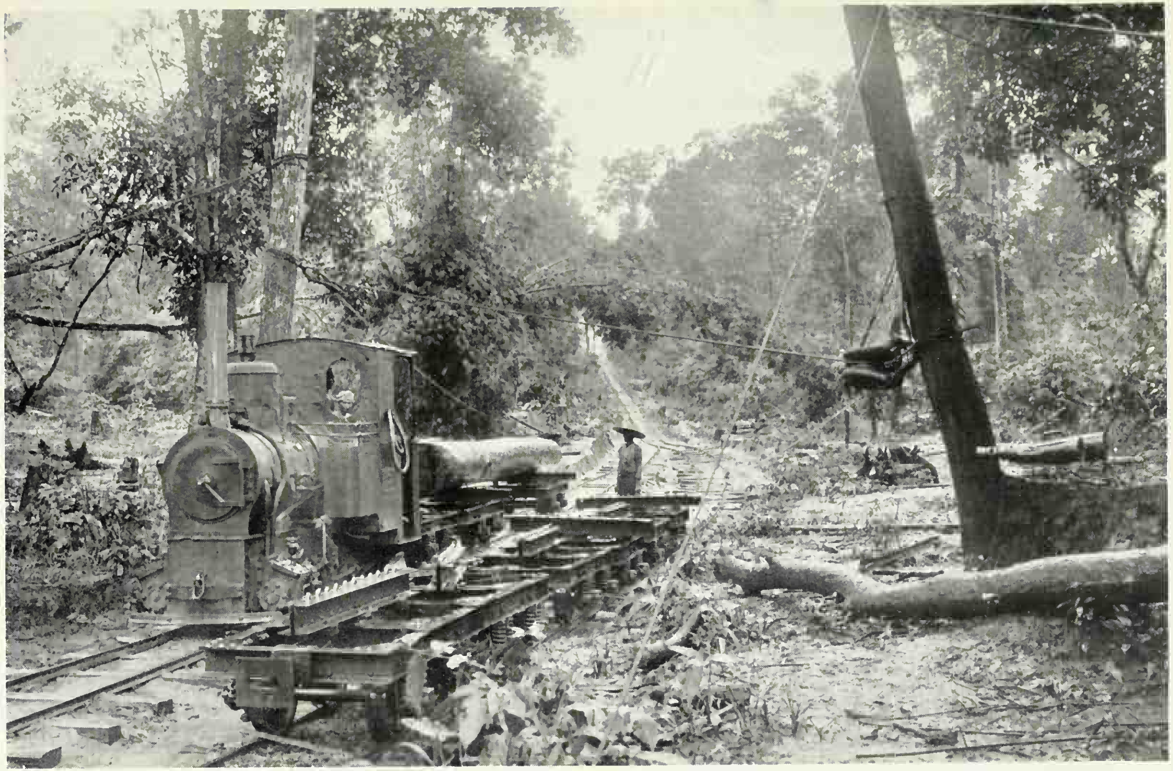
Floating streams. The clearing of floating streams is done chiefly in the dry weather. Obstructions such as fallen trees, stumps, bamboos, and rubbish, are collected and burnt. Trees which are likely to fall into the stream are felled and dragged away. Projecting rocks are blasted if necessary, and in some cases sharp bends in small streams are cut off to straighten the stream. When clearing the streams a search is made for any logs left on the banks by high floods, as these logs may often be hidden in long grass. A floating stream, during the dry season, is shown on plate XXVII.

A special method for the training of floating streams is used in the Myitmaka Extraction Division in Lower Burma, where the large deposit of silt is controlled and used to straighten the streams and to divert the channels as required. Small fences of split bamboo are made along the margins of the streams. These collect the silt and enable the formation of banks wherever required.

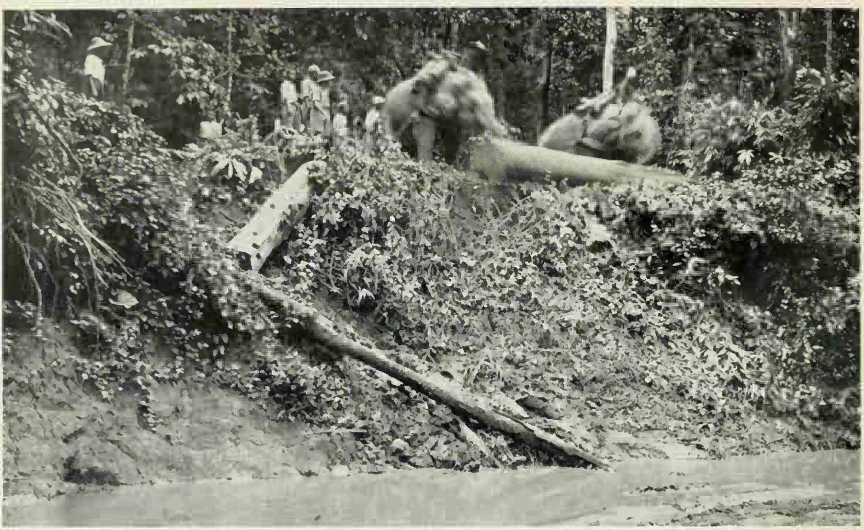
In an ordinary floating stream it is important to note the positions of rapids or waterfalls likely to damage or to hold up the logs, and also any narrow places, sharp bends, low banks, and back-waters. If the width of a stream from bank to bank at any point is less than the length of the logs being floated, jams are likely to occur; as if one end of a log strikes the bank the log usually turns completely round in the stream. For this reason timber is not usually logged longer than the width of the particular floating stream by which it will be extracted.

Low banks cause frequent trouble when floating timber, as during a flood the logs drift over the banks and get left behind when the flood ceases. If the current of a floating stream is too fast the logs are likely to be damaged against rocks; and if too slow, jams will be frequent.

Breaking a jam. A jam commences by one single log getting jammed and the remaining logs then collect behind it. If this log, which is called the *key* log, can be found and released, the whole mass of logs may move downstream. It is usually very difficult to find and remove this key log, which is often a long one, and in the case of large jams it may be too dangerous to work on the downstream side of the jam. The method then generally used is to note the point where most of the water is flowing through the jam after the flood has begun to fall and then to clear a narrow channel at this point. Small logs are first removed, either by dragging and floating them



XXV. A skidder-line used in conjunction with a forest railway to haul loaded wagons up a steep grade.



XXVI. (*a*) Launching logs into the stream bed.
(*b*) Dragging logs into position for floating.

downstream or hauling them out to the banks on the upstream side of the jam. The bigger logs are then also removed, commencing from the upstream side, until a narrow channel is cleared throughout the length of the jam. Still working from the upstream side, the remaining logs can then be hauled out of the jam and floated down the channel. The logs are usually extracted from the jam by elephants, and sometimes with a monkey-winch or block and tackle. Peavies are very useful in this work for rolling and guiding the logs while in the stream. Explosives are rarely used as they often destroy the logs without clearing the jam. It is important to get a timber jam broken up as quickly as possible before more logs accumulate behind it, as a big jam may take a week or more to clear.

Booms. These are artificial obstructions placed across a stream to intercept floating logs with the object of collecting them or diverting them into other channels. The best site for a boom is where the stream is narrow and the banks are high enough to prevent logs escaping round the end of the boom during a flood. If the current is very swift a site just below a bend is often selected, as the logs may than have lost some of their velocity before they reach the boom. A boom is usually built near the junction of a floating stream with a rafting stream for the purpose of collecting the logs ready for rafting. Booms are also used to prevent logs from floating into back-waters and side channels.

The usual type of boom consists of floating logs placed end to end and fastened together with short chains or wire ropes passed through the drag holes. The ends of the boom are anchored to firm posts, trees, or rocks on the banks of the stream. The boom is usually a single line of logs, but where extra strength is required may consist of a chain made of bundles of three logs, bound together side by side. A three-log boom prevents floating logs from escaping under the boom in rough water.

In the Salween river, booms are often made of long canes twisted together. Six to ten heavy canes are bound together, and floating logs are fastened to the boom at intervals to make it more buoyant. The boom is moored where the river is deep and the current slow.

A large number of logs are lost during floating operations, and special arrangements have to be made for the collection of stray logs and also special rules for the salving of logs and the prevention of theft. As mentioned above, the logs should be formed into rafts as soon as a suitable stream is reached, to avoid unnecessary loss.

Rafting. A rafting stream must be deep enough to float a raft

without any part of the raft touching the bottom and, except in canals, it should be wide enough to allow the raft to turn completely round. Whirlpools and partly-submerged rocks are the chief dangers in a rafting stream. Most of the rafting on the Irrawaddy River, in Burma, is done between November and March, and it takes about one month for a raft to reach Rangoon from Mandalay. About 500,000 teak logs were rafted down to Rangoon in 1927.

Construction of teak rafts. Rafts are always floated with the length of the logs in the same direction as the stream. They are made in six to ten sections, or *byits*, each consisting of from 16 to 20 logs, depending on the size of the logs and the nature of the stream. In each section the logs are as nearly as possible of the same length. The largest and heaviest timber is used in the leading sections and the smaller sized and longer timber is used for the middle and tail end of the raft. On the Sittang river small rafts are used, each containing about five sections and nine or ten logs in each section, to enable them to pass through the Pegu Canal. Plate XXVIII shows a number of teak rafts waiting for measurement in the Sittang River.

The logs in each section are usually fastened together by canes. In teak rafts the canes are passed through the drag holes and tied to poles, or *podans*, which are placed crosswise over both the front and rear ends of the sections and firmly tied down. If the logs are of unequal length the cane is passed round them instead of through the drag holes.

The raft sections are also secured together by canes. A cane is first passed through a drag hole in the rear end of a log in the leading section and the ends twisted together. The loop thus formed is then passed under the cross-pole of the next section and pulled tight by a short wooden lever or *maung-gok* about 3 feet long, the other end of which is then fastened back to the leading section. Four or five logs in each section of 16 to 20 logs are similarly fastened.

Long single logs are tied to the outside logs of two adjacent sections and serve to connect the sections together more rigidly and also to protect the cross-poles from damage.

Management of a teak raft. An Irrawaddy raft is managed by a crew of four to five men who live on the raft in a small hut, usually built on the third section, called the *te-byit*. Cane rowlocks are attached to special logs lashed to the first and last sections, and the raft is guided by four oars, two in front and two behind. The anchorage gear is usually on the second section, where a special log, called the *that-don*, is lashed down firmly to the raft near the middle, and forms a drum to which the mooring ropes are attached. When the

XXVII. Logs in the dry bed of a floating stream, waiting for the next rainy season.

XXVIII. Temporary rafts of teak logs, ready for checking and measurement.

raft is anchored it swings slowly round so that the leading section is turned upstream, and when unmoored the raft again swings round with the first section leading.

The mooring ropes are usually 4 inches in size and a coloured strand is woven into the ropes to distinguish the property of different firms and prevent theft. A coil of 4-inch rope measuring 60 fathoms weighs about 2 cwt. The ropes should be overhauled and dipped in earth-oil after each trip.

Bamboo rafts. These rafts are formed in sections or *byits* in the same way as teak rafts. The bamboos are first tied into bundles. Each bundle consists of 100 culms if the species is *tin-wa* (*Cephalostachyum pergracile*), but where the species are *kyathaung* (*Bambusa polymorpha*) or *wapyu* (*Dendrocalamus membranaceus*) only 50 culms are placed in a bundle. Ten to twelve bundles of bamboos form one section, and the number of sections may vary from ten to fifteen. The average number of bamboos contained in a raft is therefore about ten thousand.

The bamboos are held together in the bundles by cutting small holes near the ends of a group of bamboos and passing a piece of split bamboo through each culm in the group, which may consist of ten or twenty, depending on the size of the bamboos. Five to ten groups are then placed one above another in layers and tied together.

Heavy timber rafts. Non-floatable timbers such as *pyinkado* and *in* (*Dipterocarpus tuberculatus*) or *taukkyan* (*Terminalia tomentosa*) are sometimes rafted with the aid of either bamboos, or of some specially light timber such as *baing* (*Tetrameles nudiflora*) or *letpan* (*Bombax malabaricum*).

The bamboo floats are made of bundles of the same type and size as used in bamboo rafts, and in Mandalay, where this type of rafting is chiefly used, the bamboos are marketable after use on the rafts.

The logs are divided into two classes according to their sizes, and a log from 3 feet to 4 feet 6 inches in mid-girth is known as a *yat*, and a log 4 feet 6 inches in girth and over is called a *du*. Twelve *yats* or seven *dus* require twelve bundles of bamboos as floats. It takes about 6,000 bamboos to raft 100 *in* logs down the Sittang River. When *wabo* (*Dendrocalamus giganteus*) is used for floating heavy timbers it is made in the form of a raft frame instead of into bundles, and the logs are lashed to the frame.

When using light timber as floats, five logs of such species as *pyinkado* and *in* require seven large logs of *baing* as floats, and a bundle of bamboos is often attached to the sides of each section to make the raft more buoyant.

The mixed rafts which are floated down the Irrawaddy into Mandalay usually consist of 12 to 15 sections, and each section contains either 12 *yats* or 10 *dus*.

Rafting with bamboo or light timber floats is practicable only on deep rivers, such as the Sittang, and the method is not suitable for streams which are subject to very sudden rises or floods.

Use of boats. On some rivers dug-out canoes and boats are used as floats to convey heavy logs. Short cross-poles are fastened firmly across the boat and project on both sides. The logs are then secured to the cross-poles, and float partly suspended in the stream on each side of the boat. Usually from one to three logs are attached on either side. In some districts the logs are fastened to the thwarts of a boat without the aid of cross-poles. Logs cannot be transported upstream in this manner, as the fastenings break with the resistance of the water, and the use of this method of floating is very limited.

Timber is usually converted before being loaded into sea-going vessels to save waste of space, but sometimes logs in the round are shipped for special purposes. Teak timber for Europe is usually shipped in the form of 'Europe Squares', which are classified in standard sizes and qualities.

XI

WATER-SUPPLY

1. INTRODUCTION

GOOD water is one of the first requirements of health, and as water is the principal medium by which the bacteria which cause cholera, typhoid fever, and dysentery enter our bodies, if the water-supply is impure it endangers the lives of all who consume it. A careful search will usually trace the cause of an epidemic of any of these diseases to a contaminated water-supply, and a great reduction in the death-rate and in the incidence of disease invariably follows the purification of the water.

The water-supply of the Burma Forest School furnishes a good example of this. Owing to the great prevalence at the school of dysentery and other water-borne diseases the water-supply was analysed in 1925 and found to be badly contaminated. The provision of new infiltration galleries and the chlorination of the water in the storage tanks has now very greatly reduced the amount of sickness and ill health in the school.

A forest officer on tour is responsible for his own water-supply, and in this chapter we shall consider the practical measures which can be taken to ensure a safe supply of water.

Contamination of water. As water flows over the land or through the soil it picks up a great variety of substances which it can hold in solution or which can be suspended in it. In considering the question of the selection of supply and the purification of water, a clear idea of the object in view is first essential. This object is not to reject water merely because it contains foreign matter or is discoloured, but to avoid or purify water which contains anything that will cause disease. By far the most important of the things in water which cause disease are bacteria. These bacteria exist in large numbers in the excreta of persons suffering from disease, and if contamination by human excreta is suspected the water must always be considered as highly dangerous.

Water polluted with dangerous bacteria cannot be distinguished from pure water by taste, appearance, or smell. Nothing but a very careful analysis, made by a trained analyst, will determine whether water is safe or not. It can be taken for granted that most ordinary surface-wells near villages are polluted, and the measures to be taken

must be based on this assumption. No useful purpose can be gained by getting the water analysed except in special cases, but if a test is required the bottles in which samples are sent for analysis must first be perfectly clean and should be repeatedly washed out with some of the actual water to be tested. Glass-stoppered bottles are best and two quarts of water are usually sufficient. The samples must be sent to the Government analyst as soon as possible after they are collected, and in the meantime should be kept in a cool dark place where this is possible.

2. PURIFICATION OF WATER

There are various means by which water may be purified, such as by boiling, filtration, and sterilization with chemicals. In the case of town water-supplies and storage reservoirs there are many elaborate methods used for the filtration and sterilization of water, but we are concerned here only with the purification of small quantities of water for personal use.

Boiling. This is the most simple and practical method for general use. If water be kept actually boiling for one minute or longer, all the dangerous bacteria contained in it are destroyed. The water can soon be cooled after boiling by pouring it into an ordinary porous earthenware pot. Boiled water should not be kept in open vessels, and is especially likely to become again contaminated if it is stored for a considerable time.

Filtration. The two most common filters in general use are the Berkefeld pump filter and porcelain jar filters. Berkefeld pump filters are expensive and the 'candles' used in this type of filter are also expensive and need frequent renewal, as even small cracks render the filter quite useless. Unless the candles are boiled regularly the filter affords very little protection against contamination.

Porcelain jar filters are easily broken when moving camp, and are also of doubtful value unless they are kept thoroughly clean.

Chemical sterilization. There are several chemical substances commonly used for clearing and sterilizing water in forest wells and tanks. After a new well has been sunk, and also after an old well has been cleaned out, it is a good practice to sterilize the inside of the well with milk of lime. This is made by taking a quantity of quicklime and slaking it with about three times its weight of water. The solution thus formed should be used for scrubbing down the sides of the steining and will kill off all dangerous bacteria.

Muddy water in clayey soil may be easily cleared by adding a little alum. About one grain of alum per gallon of water is usually suffi-

cient. (For purposes of measurement it may be useful to remember that one cubic foot of water weighs $6\frac{1}{4}$ lb., and one gallon of water weighs 10 lb.) For purifying wells permanganate of potash is also often used, especially if the water is suspected of contamination by the bacteria of cholera or similar diseases. Sufficient permanganate should be used to give the water a pinkish colour. About $\frac{1}{3}$ grain per gallon of water is generally used and a bucket of water containing the required quantity in solution should first be made up and lowered into the well.

ERRATUM

Page 187, line 2:

for one cubic foot of water weighs $6\frac{1}{4}$ lb.
read one cubic foot of water equals $6\frac{1}{4}$ gallons.

caused by the condensation of water which has been raised by evaporation from the sea, and to some extent, from the water on the land. Part of the water which falls as rain runs into the streams and rivers, which again empty into the sea, and a vast circulation is thus kept up by the radiating power of the sun.

The rain-water that escapes evaporation from the surface of the land, and absorption by vegetation and the soil, either runs directly from the surface of the ground into the streams or rivers or it sinks into the ground. Some of it sinks into the ground at once, but a large proportion is gradually absorbed by the underlying rocks as it flows in the streams and rivers.

The ground below the surface-soil consists of a series of layers or 'strata' of different kinds and of varying thickness, as can be seen in any deep earth-cutting. Some of these strata contain sufficient crevices and openings to allow water to flow slowly through, and these are known as *permeable* strata. The rate of movement of underground water laterally is usually very slow, due to the resistance offered even by coarse sand, and the speed may be only about one mile per year. Sometimes the water flows slowly underground in great channels very similar to the rivers on the surface, but in most localities the sub-surface water occurs principally as moisture saturating the rocks.

For cities and town the water-supply is often obtained from large natural lakes or artificial reservoirs, but for villages and forest camps the water is obtained from streams, rivers, springs, or wells.

Streams and rivers. Water obtained from streams which drain uncultivated and rocky country is generally safe to use for domestic purposes, but if there are villages near the stream it will nearly always be contaminated. It has been found that running water, after contamination, purifies itself through travelling for a considerable distance in a river. This distance will, of course, depend upon the volume of the water and the extent of the contamination. Owing to the common custom in riverside villages of using the banks of a stream as a latrine, a camp should be sited *upstream* from a village whenever possible, and if a camp has to be made on the downstream side it should be sited at a considerable distance from the village. A coolie camp should always be placed downstream from your own camp, and if there are any draught animals they should be watered below both camps.

When using water from small streams in the dry weather, and in other instances when there is only a small flow of water on the surface, it is usually advisable to dig a shallow well, two or three feet deep, near the bed of the stream and a few feet away from the main flow of the water, and the sand will then filter the water percolating through into the well. The well should be small and the site should be changed frequently. It is often necessary to line the well with a split bamboo revetment. Stream and river water is especially dangerous at the beginning of the rains and during a flood, as the stream then brings down all the contaminated surface deposits from the banks, and the water used for drinking should then be carefully boiled.

Ponds and lakes. Stagnant water in small ponds is always dangerous and should never be used. Large lakes in mountainous districts, on the other hand, usually provide excellent water. In large rivers and lakes, where there are villages near the banks, all drinking water should be collected with a boat from near the middle and not from along the banks.

Springs. Rain-water percolating through a porous layer or stratum descends until it is stopped by an underlying impermeable stratum, over which it flows. This underlying stratum is usually not quite horizontal but forms ridges and hollows, sometimes roughly corresponding to the hills and valleys on the surface. The rocks forming the impermeable stratum sometimes emerge at the surface of the ground, and this is called an 'outcrop'. If the outcrop is at a low point the water flowing over the stratum will emerge in the form of a spring.

Spring-water is nearly always wholesome and uncontaminated

owing to the thorough filtration it has received in passing through a considerable thickness of porous soil before issuing as a spring. It usually, however, contains salts or sulphur compounds dissolved from the rocks through which it has passed, and if these are in large proportions the water may only be fit for medicinal purposes.

Wells. Wells are divided into three types: (1) shallow wells sunk into sand, or other permeable strata, a short distance below ground surface; (2) 'deep' wells carried down by boring to considerable depths through impermeable strata into underlying water-bearing rocks; (3) tube wells in soft soil. 'Deep' wells require special boring appliances and machinery and are therefore not practicable for forest work, and we have nearly always to depend on tube wells or 'shallow' wells.

(*a*) **Tube wells.** These are specially useful for supplying water to temporary camps, particularly during the hot weather. They are often sunk in the sandy beds of streams when the water-level has sunk too low to be reached by other means. In sandy soils, tube wells can be sunk much more cheaply and rapidly than ordinary wells; and they are sometimes used for testing the sites of proposed masonry wells. The necessary materials for a tube well can be easily transported, and when the well is no longer required the tubes can be extracted from the ground and used elsewhere. The construction of tube wells is explained on page 197. They cannot be used successfully in rocky ground or in heavy clay soils. Their maximum depth is limited by the necessity of using a valve pump, which can only raise water for about 20 feet in actual practice, allowing for air leakages and imperfect joints.

(*b*) **Shallow wells.** Shallow wells sunk to a maximum depth of 35 or 40 feet are the most usual type of forest wells. If these wells are made with a waterproof steining, and are also protected at the surface from drainage, the water will be fairly pure, as it will have filtered through a considerable depth of soil. The thoroughness of the filtration will vary according to the nature of the soil.

4. SINKING OF SHALLOW WELLS

Selection of site. The safety of a shallow well depends largely on the position of the well in relation to houses and other sources of contamination. A well should never be sunk near latrines, cattle-sheds, burial-grounds, or stagnant pools. The choice of site is usually very limited, as it must be within a convenient distance from the buildings to be supplied. Wherever possible a test well should be sunk or some other means of water-supply assured before a building

is erected, as it may not be found possible to obtain a plentiful supply of good water within reach. In very rocky ground it is almost impossible to make a well without special boring machinery. The well should usually be situated at a low level in order to reduce the depth of excavation as much as possible, but it must not be sited in the very lowest place or it will be very difficulty to arrange for surface drainage away from the well.

Water will usually be found near the surface in places where grass remains green during the hot weather. Springs are often indicated by insects hovering in a column, and remaining in one place, at a fixed height from the ground. In the early mornings and evenings denser vapours arise from over springs than from other parts of the surroundings.

Any large trees near the site should be felled, as tree roots often penetrate and damage the lining, and unless the well is covered, leaves and branches will fall into the water.

Depth of wells. The depth may sometimes be indicated by the depth of existing wells in the neighbourhood, but it is impossible to find the depth of a proposed well without making actual borings on the site, and this is not usually practicable in forest work. Lime-stone is permeable and in limestone country the wells are usually very deep.

The depth from the ground to the surface of the water in an existing well of moderate depth may be ascertained approximately by noting the time occupied by a pebble in dropping; the depth in feet being sixteen times the square of the number of seconds occupied in the fall. For example, if the time occupied is 2 seconds, the depth will be $16 \times 2^2 = 64$ feet.

It is usual to include in the conditions of a contract for well-sinking that the contractor will undertake to sink the well to such a depth that it contains 4 feet of water on April 1st, or at some other suitable date near the end of the dry weather. The rate per foot of depth paid for excavation will increase directly according to the depth of the well, and it is usual to increase the rate after each 10 feet of depth. To assist in the subsequent cleaning of a well the original depth should always be indelibly marked near the top of the masonry steining.

Excavation. Wells should be dug in the hot weather while the water-level is low. The method of excavation will depend on the nature of the soil. If the soil is stiff the digging may be carried down vertically until the water-level is reached, but if it is sandy or unstable an unlined well can only be safely excavated with sloping sides. In such soils a curb-plate may be laid on the surface of the ground and

the steining sunk gradually as the soil is excavated from beneath, as described below.

The form of the excavation will depend on the kind of steining to be used. Masonry steining is nearly always circular, and timber linings are often square in section. A small windlass is usually erected over the well for removing the excavated soil.

Design for small masonry well. A simple masonry well is shown in fig. 72. The steining consists of radially shaped bricks and is 9 inches thick. It is supported on a wooden curb at the bottom and is carried up to a height of 3 feet above ground level. The curb is made in three layers, each layer consisting of several sections, the whole curb being bolted together by $\frac{1}{2}$-inch bolts; the joints overlapping and well strengthened by iron fish-plates on the upper surface. The lower outer edge of the curb is fitted with an iron cutter in the form of a ring 3 inches deep by $\frac{1}{2}$ inch thick. The most suitable timber for a curb is *letpan* (*Bombax malabaricum*) or *mango* (*Mangifera spp.*).

To secure the curb to the masonry and to prevent the lower part of the cylinder getting detached during sinking, or through subsequent settlement, six iron tie-rods, 10 feet long, are built into the steining of the well from the bottom of the curb, their upper ends being connected under the bolt-heads by a bond plate, formed by an iron ring $4 \times \frac{1}{2}$ inch in size.

An apron or platform of concrete, 4 feet 6 inches wide, surrounds the well and is given an outward slope. The apron is bounded by a brick curb raised 6 inches above the surface-level, and this conveys the water to a masonry-lined drain which conducts it to a safe distance of about 20 to 30 feet from the well. This drain is not shown in the drawing through lack of space. A cover of one-inch tongued and grooved boarding is fitted over the mouth of the well, and a wooden pulley or roller for a rope or chain is supported on a light frame of 4×4-inch timber, the two posts of which are sunk into the ground before the concrete apron is laid.

Well steinings. Permanent forest wells are usually constructed with masonry steining for the whole depth of the well, but temporary wells may sometimes be lined with timber or with corrugated iron.

When wells are excavated in hard ground and no lining is required to hold up the soil, a steining should be provided for a depth of at least 8 feet to prevent pollution from surface drainage. When a steining is used in this way for the top portion only, the diameter of the well-shaft below the steining must be at least 2 feet less than the diameter of the upper portion of the well, to form a firm foundation to take the weight of the curb of the steining.

The usual type of masonry steining for small wells consists of one single brick 'ring' of radially-shaped bricks or stones, or of coursed stone rubble. If the well is more than 10 feet deep, and the soil is very unstable, two brick rings of 9 inches each should be used, thus making the steining 18 inches thick. The bricks should be of good quality and should be tested as described in Chapter I. Large stoneware or concrete pipes may also be used as steining.

To assist in keeping out surface-water it is advisable, when filling up the excavation, to back the steining with puddled clay 6 inches thick for 8 to 10 feet from the surface. The mortar used in the brickwork should be made of good hydraulic lime or of cement. The inside of the steining should also be lined with cement plaster $\frac{1}{2}$ inch thick which should be continued down nearly to the bottom of the well.

Sinking masonry steining. A well with a brickwork steining is usually constructed by carrying down the excavation as far as possible and then laying a wooden curb on which the steining is built (see figs. 70 and 71).

For shallow wells in Burma it is nearly always possible to dig down to water-level before it becomes necessary to lay the curb and build the steining. The weight of the brickwork is then used to sink the steining for the last few feet by excavating evenly under the curb and building up the additional layers of brickwork on the top. The great difficulty is to ensure that the shaft is kept quite vertical. This should be continually tested by three plumb-lines suspended from the top of the well. If, when sinking the well from the top, the friction of the earth on the sides becomes so great that the steining is held up, extra weights are added to the top of the brickwork.

In cases where the hard nature of the ground prevents the steining from being sunk any farther by weights from the top, it is left suspended, and a second curb is laid at about 8 feet below the first, the brickwork then being built up from the bottom curb to meet the original curb. This method is very dangerous, and when it is used for deep wells the upper section should be temporarily suspended by long iron tie-rods from the top of the well. Several sections may be built up in this way, each section being suspended in turn from the section above.

Another method is by *underpinning*. In this the excavation is first made of full size, to the maximum depth at which the soil will stand without support, and a strong wooden curb is then laid and the steining built up to the top as before. Then, in the centre of the bottom of the well, a smaller shaft is dug again to the depth which the earth will safely stand. A hardwood block is placed at the bottom of this shaft in the centre, and sloping props or struts are

WELL-SINKING

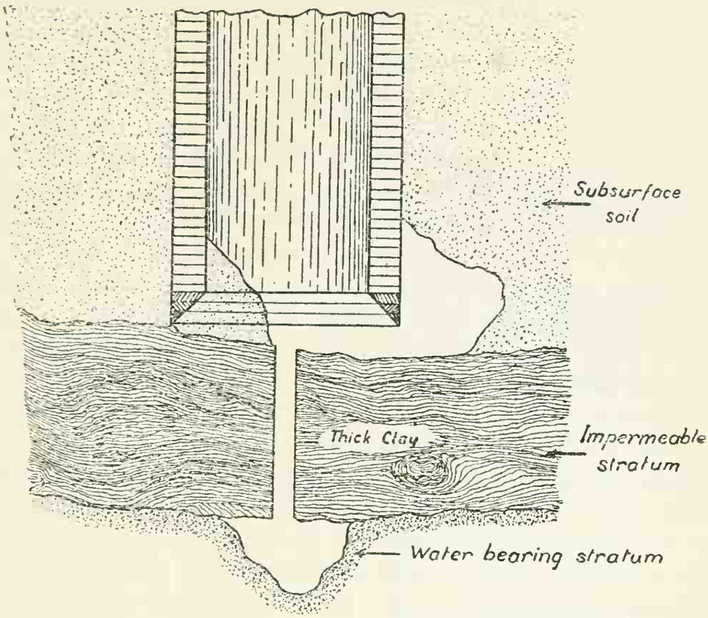


FIG. 70

UNDERPINNING

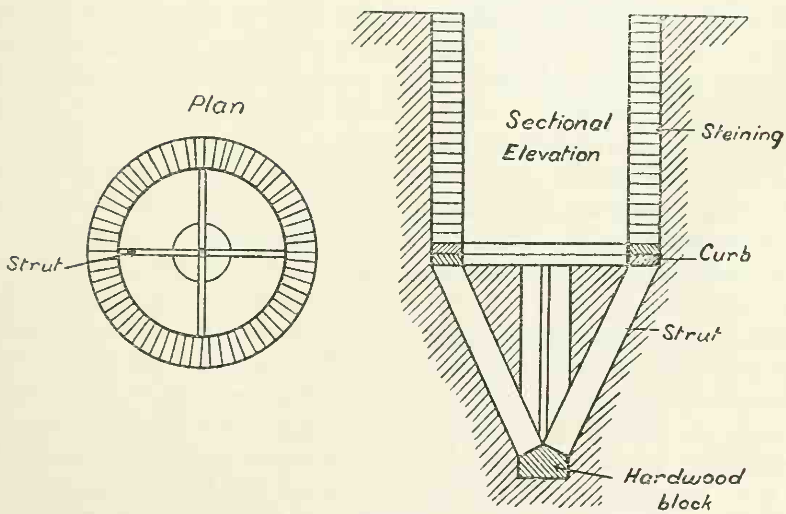


FIG. 71

inserted under the completed steining, butting against this central block (see fig. 71). Sufficient earth is cut away to enable these props to pass from the central block to the steining. The curb with its load of brickwork is thus supported by the props, and it is possible to enlarge the pit to its full size. Another curb is then set at the bottom of the new shaft and the new brickwork built up to form a permanent support to the first section. The props are then removed and the whole operation is repeated until the required depth is reached. Instead of wooden struts, narrow pillars of brick are sometimes used to support the steining and are laid in vertical recesses cut under the curb, leading outwards from the central shaft.

If a thick bed of clay is reached after digging has proceeded to a considerable depth and the amount of water is not yet sufficient, the excavation should continue for another 2 feet to give the well-steining a firm foundation, and then a hole about 6 to 9 inches diameter should be made in the middle of the well. If the steining is not firmly embedded in the clay the well is likely to get silted up, and may also be undermined, as shown in fig. 70. The hole is made with a 'jumping bar', or, if available, with a special boring auger; sharpened bamboos are also sometimes used. The object of this central hole is to penetrate the bed of clay down to the sand which contains the water below. When the sand is reached the water will pass up through the hole into the well and bring sand with it, and will usually continue to come up as the water is drawn from the well. It is unnecessary to line the hole with a pipe, as it usually keeps open and gets gradually enlarged by the passage of the water and sand.

Timber-lined wells. When timber is used to line a well it tends to decay rapidly, and frequently causes a discolouration of the water. Hence it is useful for small temporary wells for one or two seasons only, but should not be used for permanent forest wells as it cannot be made sufficiently watertight to keep out surface drainage.

A timber-lined well is usually made square in section, and a square with sides of 4 feet is a convenient size. If the well is not more than about 16 feet deep the whole lining is sometimes built up outside the well and dropped into position after the excavation has been completed. For deeper wells a series of frames of timber, 4 or 6 inches square, are placed at vertical intervals of about 4 feet, and planking or sheeting, 2 inches thick and 10 inches wide, is placed behind them to form the lining. The frames or 'sets' are kept in position by vertical wooden struts spiked at both ends to the frames. This form of lining is usually built from the bottom by 'underpinning', as in the case of masonry wells.

SIMPLE MASONRY WELL

(4 feet diam)

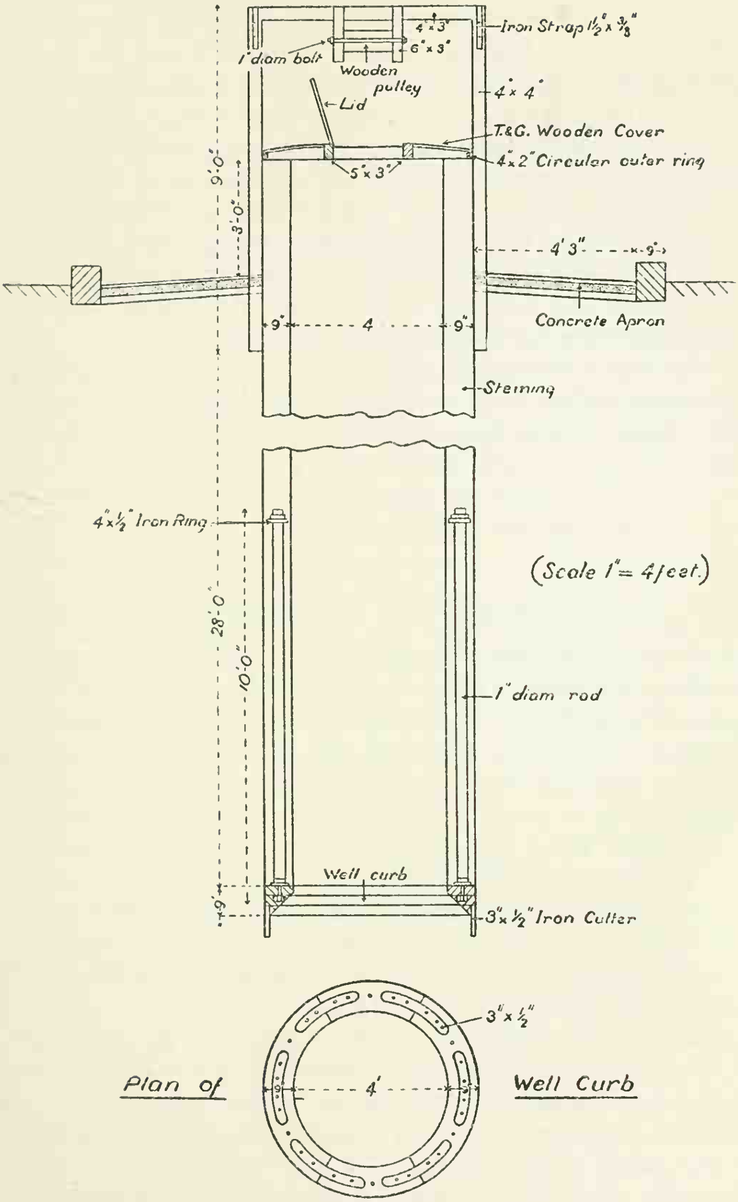


FIG. 72

A better method, if the soil is unstable, is by means of 'cases'. A case is simply a square frame of four 3-inch planks made like a box, but without either a lid or bottom. The side-planks are cut with a tenon at each end, one-third of the width of the planks, and the end-planks are notched at each end to receive the tenons of the side-planks. The first 'case' is placed in position on the ground surface, and other cases added below piece by piece as the excavation proceeds. One side of a case is placed in position first, then one end, then the other side, and lastly the remaining end. The cases must all be exactly flush with one another on the inside and fit close together. This method makes a stronger casing, but takes more labour and more timber than the frame and sheeting method, and is generally used only for wells of large diameter and in deep shafting for mines.

Corrugated iron lining. This is often used for the construction of temporary wells. The corrugated iron sheets are usually placed behind square timber-frames, as in the case of timber sheeting. Corrugated iron may also be used alone bent into the form of large cylinders with the edges overlapping and bolted together, as in the case of a corrugated iron culvert.

5. PROTECTION AND CLEANING OF WELLS

The masonry steining is usually extended to form a parapet wall 3 feet above the surface level of the ground. In addition to this all wells should be protected from surface-drainage by a water-tight apron or platform surrounding the well, and drained by a masonry-lined drain for a distance of at least 20 feet from the well, as already explained. Where possible this platform should not be constructed until one whole rainy season has passed since the excavation of the well, or the settlement is likely to cause cracks in the concrete later.

Covers. Covers are often omitted from forest wells for economy, but their cost is small if they are of the type shown in fig. 72, and they should always be fitted when the well is near a road or a village to prevent dust from entering the well.

It should be noted that the most dangerous source of pollution is from direct contamination by the users of the well. The washing of clothes at the well cannot always be prevented, but if a cover is provided it prevents villagers from hanging their dripping clothes over the edge of the parapet of the well, which is the usual custom with open wells. A fence should also be built round the well to keep out cattle. Well-water is often dangerously contaminated through vessels, which have been brought from houses where an infec-

tious disease is prevalent, being dipped into the well. A bucket, chained permanently to the well, may prevent this.

Roofing of a well with shingles, boarding, or corrugated iron, is not so efficient as a cover and is more expensive. A thatch roofing should never be used as it harbours bats, rats, and birds, the droppings from which contaminate the water.

Cleaning. Wells should be cleaned out thoroughly every year. The best time is at the end of the hot weather when the water-level is low, but in the case of a well which has been allowed to remain stagnant for a considerable period, the stagnant water must always be removed before the well is again brought into use, regardless of the time of the year.

If the well is deep the air should first be tested by lowering a lighted candle down to the surface of the water before a man is allowed to descend to clean it out. If the candle goes out, the bad air near the bottom of the well can be removed by repeatedly lowering and raising a large bundle of leafy branches or straw, which will carry down good air into the well.

When a well is being cleaned care should be taken to see that all mud and sediment in the well is removed until the *original bottom* is reached. The sides should be scraped, and the masonry lining should be examined thoroughly, and any cracks repaired with cement. After the well has been cleaned, about 80 to 100 lb. of charcoal should be thrown into the water, as this tends to absorb any impurities.

Wells which have been considered safe for several years may later become dangerous because the soil loses its power of filtration when saturated with sewage, and in bad cases it may be advisable to dig a new well on a different site.

6. DRIVEN TUBE WELLS

Construction. The well consists of a tube which is driven down into the ground by means of a special monkey attached to the tube itself. Plate XXIX shows a tube-well being driven by the Burma Sappers and Miners at Mandalay. In this case it is sunk near to a small muddy stream to obtain clear water, which will be filtered through a depth of 20 feet of soil before it reaches the bottom of the tube-well.

The tubes forming the well are of iron, and have an internal diameter of $1\frac{1}{4}$ inches. Each tube is fitted at one end with a barrel-shaped socket $2\frac{1}{2}$ inches long, which has a screw thread to fit the tubes. The first length of the tube has a steel point welded into it, and above the point the tube is perforated with about 300 small holes $\frac{1}{8}$ inch in diameter. The well is driven into the ground by

blows delivered on a driving cap or clamp, which can be seen in the photograph. The blows are given by a cast-iron monkey weighing about 84 lb., which has a hole through the centre, and slides freely up and down the tube. Two ropes are connected to the monkey and pass over small pulley-sheaves as shown.

Driving the well. The site for the well having been selected, a hole is first made with a crowbar and the well tube inserted to a depth of about 2 feet. The driving clamp is then screwed firmly to the tube about 2 feet above the ground, each bolt being tightened equally so as not to indent the tube. If the ground is soft a driving cap may be used, attached to the top of the tube, instead of the clamp. The monkey is placed on the cap or clamp, and the pulley-bar then inserted in the tube. Ropes are tied to the monkey and passed over the sheaves of the pulley-bar.

The monkey is raised by two men pulling the ropes at the same angle, as shown in plate XXIX. They should stand exactly opposite to each other, and work together and pull very steadily so as to keep the tube perfectly vertical while being driven. Only short blows should be given at first, and if the tube shows an inclination to slope towards one side, guy-ropes should be fastened to the top of the pulley bar and held by four men, as shown in the photograph. When the monkey has been raised to the top it is allowed to descend with its full weight on to the clamp.

The bolts on the clamp must be frequently tightened so that it does not move on the tube. When the clamp has been driven down to the ground the screws are slackened, and it is raised up the tube to a height of 2 to 3 feet, and again screwed on firmly as before. When one length of the tube has been driven in, a fresh length of tube is screwed on so that the two tubes butt tightly against each other. A little red lead should be placed on the screw threads to make the joint air-tight. Driving can then be resumed, but after a few blows the tube joint and the clamp should again be tightened.

Care should be taken not to drive right through a water-bearing stratum, and before screwing on additional lengths of tube the well should always be sounded by means of a small plumb-line inserted down the tube. This will show the depth of water, if any, and also the nature of the soil which has penetrated the perforations.

The whole process is very simple, and tube-wells can be driven at the rate of 12 feet an hour in flinty chalk and 20 feet in soft soil. Five or six men are required if the work is to be done quickly.

Withdrawing the tubes. In soft ground the tube may be withdrawn by simply turning it round with tongs, right-handed so as

XXIX. Burma sappers and miners driving the first section of a tube well.

not to unscrew the joints, at the same time lifting upwards. If the ground is very firm it may be necessary to use a wooden lever and a rope or chain fastened round the nearest joint, but care must be taken not to bend the pipe, as if once bent a pipe is no further use for driving. To loosen the tube, if it is sticking, the monkey may be placed upside down on the tube with the clamp above it, and a sharp upward blow given against the clamp.

Tube-well pump. The water is raised by means of a special pump provided with the set. This pump is screwed on to the top, and it is particularly necessary to make the top joint air-tight with red lead, or the air will be heard hissing through when the pump is worked. To start the pump it is necessary to pour a little water into the top, and to pump for a few minutes to exhaust the air which is in the tube.

When pumping has been started the pump handle should first be worked vigorously, and then it should be raised and held for a minute or two. By a special arrangement of the valves in the pump this causes the water to drop down the tube and clear away the mud and fine sand which has accumulated inside and around the filter point during the driving. Pumping should be continued until no more sand comes up with the water.

When sinking in certain kinds of soil, the bottom of the tube often becomes choked, and a special set of cleaning tubes is supplied with the pump to reach down inside the well-tube. Water is poured down between the tubes, and the mixture of mud and water which is choking the well is then gradually pumped up through the cleaning tubes.

If the well is to remain out of use for some time the pump should be removed and replaced by an iron cap screwed on the top of the tube.

The water from driven tube-wells is cleaner and much less liable to pollution than the water from open wells, but, as already stated, a driven tube-well can only be used successfully under certain conditions of soil and depth, and although the apparatus is very simple it requires a certain amount of care in handling until the men get accustomed to the work. Spare washers and pump-valves should be kept available to replace parts worn out, and it is probably owing to the difficulty in inducing subordinates to look after these details that tube-wells are not more generally used in the Forest Department.

XII

MISCELLANEOUS

IN this chapter we shall deal briefly with a few simple engineering contrivances commonly used in forest work, and which have not already been discussed. We shall also consider the construction of several minor forest works, such as fencing and boundary pillars.

1. LEVERS, ROPES, AND ANCHORAGES

Levers. Levers are used extensively in forest work, in one form or another, and much unnecessary labour is often caused because the simple principles upon which they depend are not clearly understood.

Any rigid bar which is moved about one fixed point is a lever. The bar may be straight, as a crowbar, or bent, as in the case of a claw-hammer used to extract nails. The two most common methods of using levers are shown in figures 73 and 74. The fixed point, F, on which the lever moves, is called the *fulcrum*. In fig. 73 the block of stone at C is being raised by the force applied at P, and the weight of the load falls between the force and the fulcrum F. In fig. 74 the weight is at the end of the lever, and the fulcrum F is between the weight and the point of application of the power. In both the above cases the length between the point of application of the power and the fulcrum is called the *lever*, and the length between the load and the fulcrum is the *counter-lever*.

Now in all forms of levers the advantage gained depends directly upon the proportion between the respective lengths of the lever and the counter-lever. The greater the length of the lever and the shorter the length of the counter-lever, the greater the advantage gained.

If the lever is quite straight, and both the power and the load are applied at right angles to the lever, the amount of power required is equal to the weight of the load multiplied by the length of the counter-lever and divided by the length of the lever. For instance in fig. 73 the power P, required to raise a weight of 100 lb. at C, by a lever with a total length of 6 feet, and a counter-lever of 2 feet in length, is approximately equal to $100 \times \frac{2}{6} = 33\frac{1}{3}$ lb. In fig. 74 the length of the lever is only 4 feet and the effective length of the counter-lever is one foot. The power required is therefore $100 \times \frac{1}{4} = 25$ lb.

It is important to note that the lengths of the lever and counter-lever must be measured at right angles to the direction of the force

Use of Levers

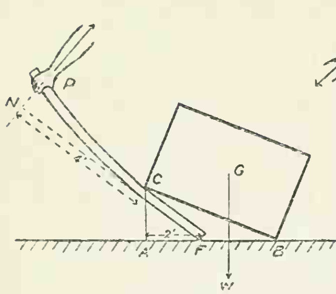


FIG. 73

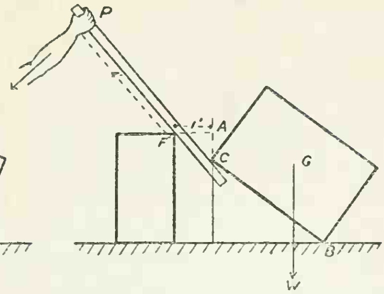


FIG. 74

Timber hitch

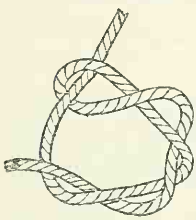


FIG. 75

Clove hitch

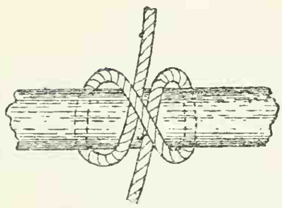


FIG. 76

Guide block

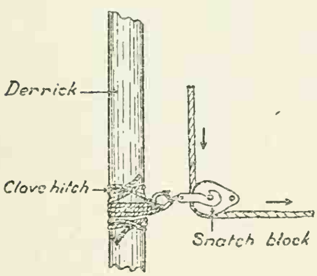


FIG. 77

Post Anchorage

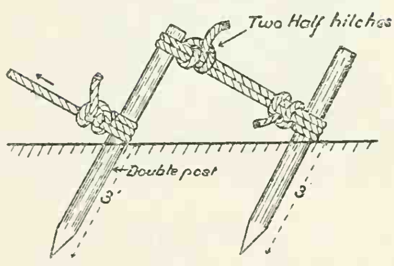


FIG. 78

applied, and as the lever, *PF*, in fig. 73, is not straight, the effective length of lever is *NF*; and the length of the counter-lever is *AF*. In fig. 74 the effective length of the counter-lever is only *FA* and not *FC*, as the load is acting vertically downwards.

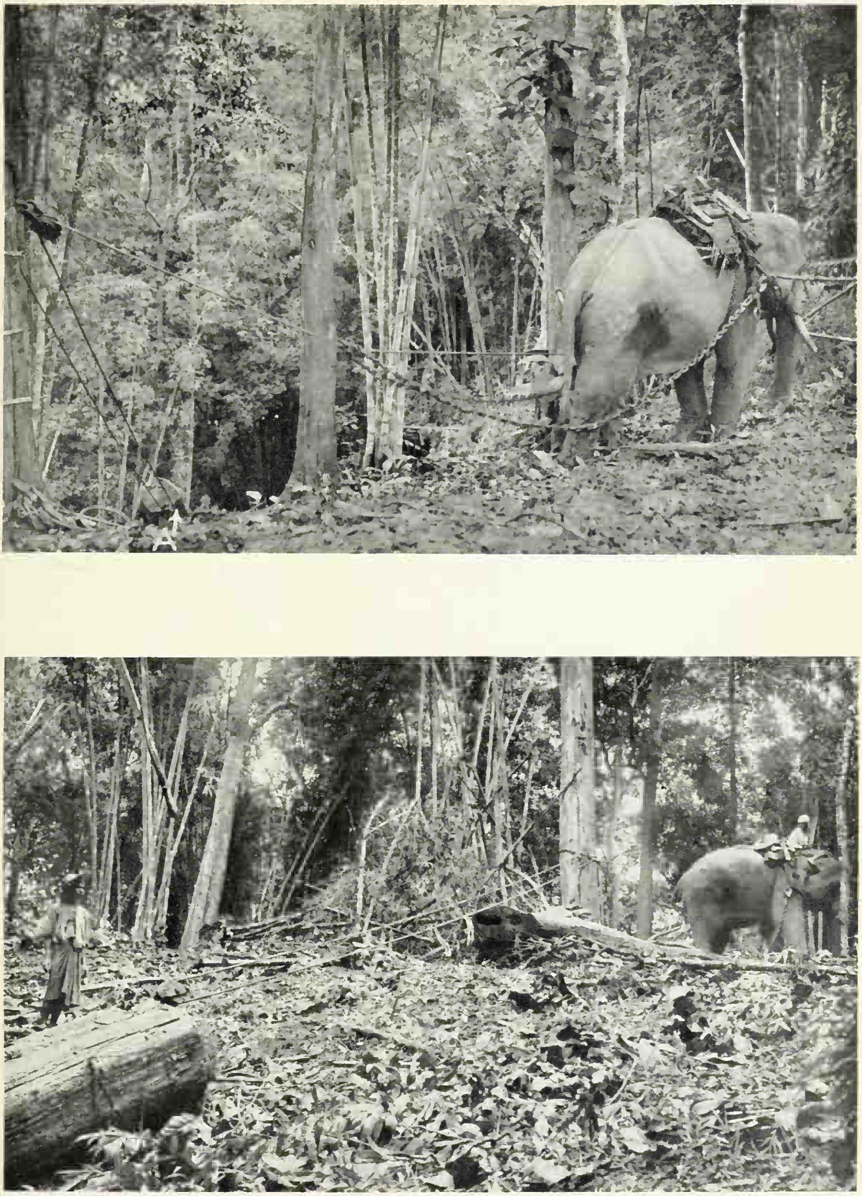
Centre of gravity. In raising a large block of stone, as in figs. 73 and 74, or in erecting a heavy post by levers, we find that the higher the block or post is raised the less power is required. This is due to alteration in the position of the 'centre of gravity'. The centre of gravity of any mass of material is the point about which it would balance, in any position, if that point were supported. For instance a uniformly shaped log will balance about its middle point and a wheel will balance about its centre.

The advantage of knowing the position of the centre of gravity is that, in dealing with forces acting on a body, the whole weight of the body may be supposed to act at its centre of gravity. The point *G* in figs. 73 and 74 represents the centre of gravity of the stone block. It will be seen in fig. 74 that a perpendicular, *GW*, dropped from the centre of gravity, is nearer to the point of support *B*, than in fig. 73. As the block is slowly raised this perpendicular gradually approaches the point *B*. The power required to raise the load steadily decreases as the line of the centre of gravity approaches the point of support, and when the centre of gravity is exactly over the point of support the load will balance.

The above principle may be applied when a falling tree is caught up in the branches of an adjacent tree. If the tree remains nearly vertical the centre of gravity will be almost over the butt, and the effective weight of the tree is so small that the resistance of the boughs of the adjacent tree is sufficient to keep the tree from falling. If the butt of the felled tree can be moved by levers for a few feet outwards, so that the line of the centre of gravity falls farther away from the base, the increase in the effective weight is often sufficient to overcome the resistance of the boughs, and the tree falls.

Ropes. The chief requisites of rope are strength, suppleness, and durability. Ropes are made of hemp, manilla fibre, and coir. Hemp rope is the strongest, but manilla rope stands exposure to weather and rain much better. Coir is very weak, but it is light, will float on water, and does not rot. It is much cheaper than manilla rope, and is suitable for rafting and similar purposes.

A new rope tends to twist badly, and it must always be stretched before use. Rope should be allowed to dry before being put into store, and should be dipped in earth-oil at the end of the season. When using rope it should be kept from chafing against sharp edges,



XXX. (*a*) Using single-whip tackle to raise log, shown at 'A', from deep ravine.

(*b*) Dragging log with single tackle. The moving block can be seen attached to the end of the log.

as far as possible, by interposing rollers and by rounding off the bearing surfaces.

The size of a rope is denoted by its circumference in inches and its length in fathoms. A fathom is 6 feet, and rope is usually manufactured in coils of 113 fathoms. Rope is generally sold by weight, and 3-inch manilla rope weighs about 1 lb. per yard. $1\frac{1}{2}$-inch rope is the best size for lashing spars and for scaffolding. Before a rope is cut through, the two portions close to the cut should first be bound for about $\frac{1}{2}$ inch with a piece of thin string, to prevent the ends of the rope from untwisting and fraying.

Strength of rope. If C be the circumference of a rope in inches, then for ordinary rope the safe load is C^2 cwt., and for steel-wire rope it is $9C^2$ cwt. For example, a wire rope of 3 inches circumference, such as is used for the main cables on a light suspension bridge, will stand a straight pull of 9×3^2 cwt. $=81$ cwt., or just over 4 tons. The strength of a rope when slung over hooks, or fastened by knots, is reduced, and the safe loads should then be taken as about two-thirds of the above loads. Ordinary rope shrinks when wet, and when thoroughly saturated is weaker than when dry.

Simple knots. The two most useful knots for forest work are the 'Clove hitch' and the 'Timber hitch'. These are both very simple to make, and can be seen in use wherever round timber is being used in construction.

The clove hitch (see fig. 76) is used for the commencement and finish of rope lashings, and also for attaching guy-ropes to posts or derricks. The timber hitch (see fig. 75) is made by simply twisting the free end of the rope back on itself, thus forming a loop round the standing part. It is used for holding or dragging timber where the weight will keep the hitch taut.

To lash a block to a spar. When it is necessary to lash a pulley-block to a post, tree, or spar, the back of the hook is laid against the spar, a clove hitch is taken round the spar above the hook, then several turns round the hook and spar, and the rope is finished off with two half-hitches round the spar below the hook, as shown in fig. 77. The hook should be prevented from slipping off the lashing by taking a few turns round the end of the hook with thin coconut-fibre cord, as shown in the figure, and these turns should be tightened up by a few frapping turns to hold them in position.

Anchorages. In forest work it is usually possible to use a tree or tree-stump for a rope anchorage, but where a suitable natural anchorage is not available a good substitute can be quickly made by driving two short posts close together, 3 feet into the ground,

sloping slightly outwards from the direction of the pull, and tying them back near their tops to the base of a third post driven into the ground at a distance of about 6 feet behind them (see fig. 78).

In sandy places, and also for more permanent requirements such as for a suspension bridge, a buried log makes the best anchorage. A trench is dug of sufficient length to hold the log, which should be about 3 feet in girth and 6 feet long, and the rope or cable is given one complete turn round the log and then taken up through a narrow incline dug at right angles to the trench. The trench should be dug at such a distance away that the slope of the cable or rope is not steeper than about 1 in 3. For additional safety two short posts are often driven into the ground in front of the log to hold it in position.

2. BLOCKS, TACKLES, AND THE USE OF SPARS

Pulley blocks are used for the purpose of changing the direction of ropes or of gaining power. They are called single, double, or treble blocks, according to the number of sheaves which they contain. The sheaves revolve on an iron pin, which should be kept well lubricated with grease or oil. The diameter of the sheave is dependent on the size of rope to be used; if the sheave is too small the strength of the rope is diminished, and a proportion of the power is also lost. On the other hand, the smaller the sheave, the lighter is the block. For wooden blocks the length of the shell of the block should be roughly three times the circumference of the rope to be used. Iron blocks have a shell of a slightly less proportionate length. Wire ropes should always have plenty of room in the block and the diameter of the sheaves should be roughly six times the circumference of the rope.

'Snatch blocks' are single blocks with an opening in one side of the shell to admit a rope without threading its end through the block. The opening is usually closed by a hinged iron strap, as shown in fig. 77.

Tackle. Any combination of ropes with one or more pulley-blocks is called a *tackle*. The rope with which a tackle is *rove* is called a 'fall'. The *standing end* of the fall is the fixed end, and the other is the *running end*. A tackle is 'rove' by two men standing back to back, about 6 feet apart. The blocks are laid on their sides between the feet of the men and with the hooks to the front. A coil of rope is placed to the right of the block which contains the largest number of sheaves, and beginning with the lowest sheave of this block, the end of the fall which is to be the 'standing end', is placed successively through the sheaves of both blocks from right to left and then made fast.

TACKLES

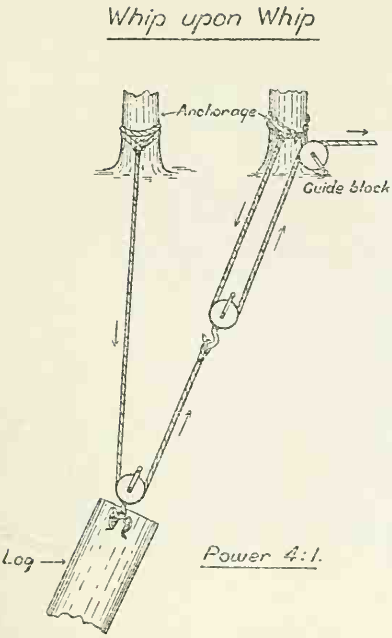


Fig. 79

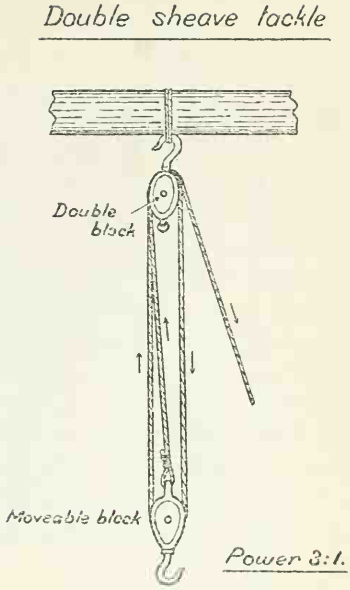


Fig. 80

BOUNDARY PILLARS

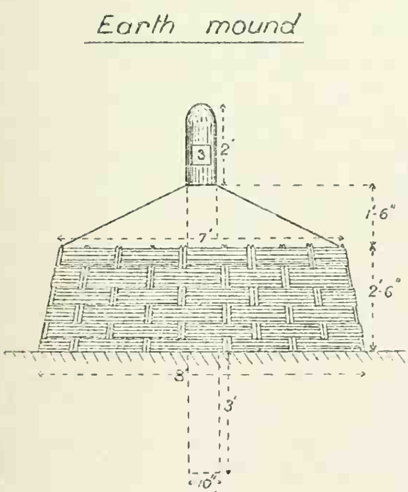


Fig. 81

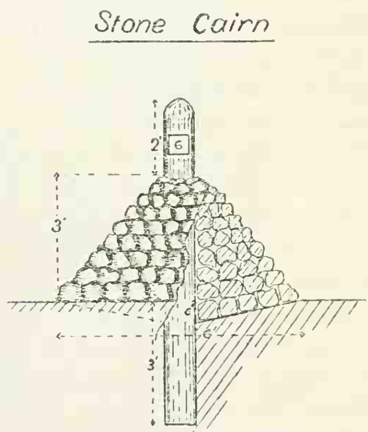


Fig. 82

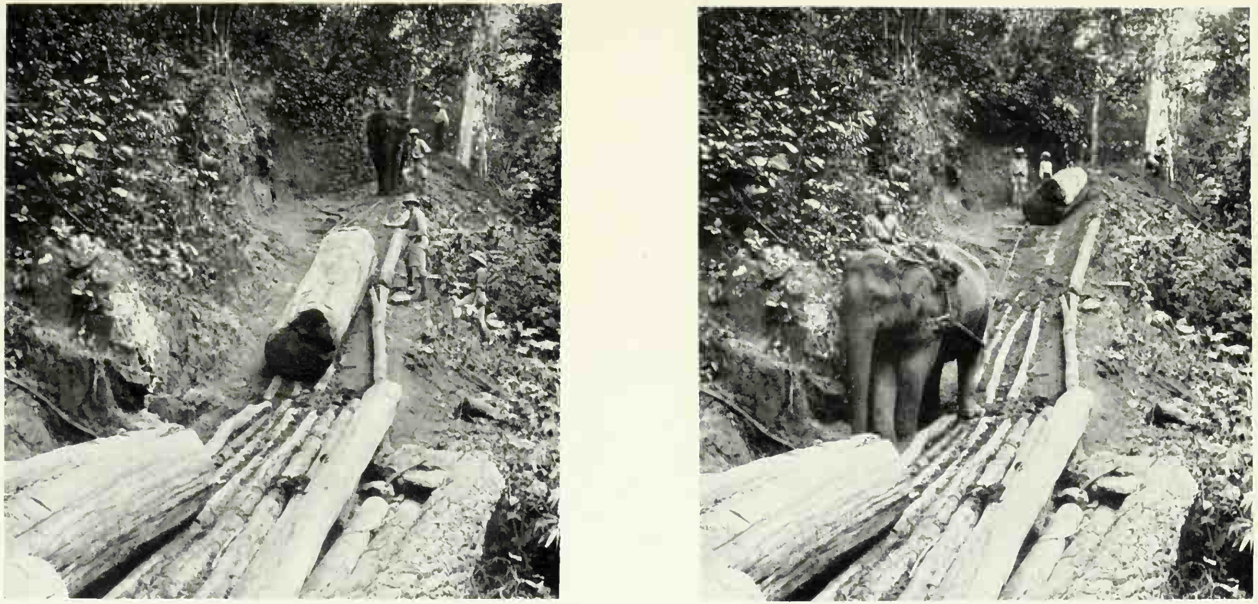
The simplest form of tackle is a *whip*, which is a single movable block, rove with a rope or cable, one end of which is tied to an anchorage tree or holdfast while the other end is the hauling rope. This is the most common form of tackle used for hauling logs up steep grades by elephants. The moving block is fastened directly to the drag hole in the log. One end of the wire rope is attached to a tree, and the other end is passed through the moving block and then through a fixed guide-block or snatch-block, which is usually attached to the anchorage tree (see plate XXX). In the upper photograph the guide-block is seen on the extreme left, and the whip-tackle is shown attached to the end of the log, *A*, which is being dragged out of a deep ravine. In the lower photograph the whip-tackle can be clearly seen attached to the log, and the guide-block and fixed end of the rope are both attached to the same tree. The use of a guide-block enables the power to be applied from any convenient direction, which is usually either along a ridge or downhill. In plate XXXI which shows the lower portion of a block-and-tackle dragging path, the guide-block is attached to a tree near the top of a ridge and, by means of the whip-tackle attached to the drag hole, the log is hauled up the slope as the elephant descends.

When using tackle with derricks or sheers, the running end of the 'fall' should always be led through a leading-block lashed to one of the spars at a few feet above the ground. A snatch-block is the most convenient for the purpose (see fig. 77).

Power ratio of tackle. The power obtained from a pulley-block depends directly on the number of ropes supporting the movable block. In the single-whip tackle described above, the power of the haul is increased by two. This advantage of power can be again doubled by inserting a second whip in the tackle as shown in fig. 79. The arrangement is then known as a 'whip-upon-whip' tackle, and is often used for dragging heavy logs.

When tackle is used in conjunction with spars, as in a derrick, the power is usually increased by the use of pulleys with several sheaves. A very common arrangement of tackle is shown in fig. 80, where a double pulley is used at the top or fixed block, and a single pulley for the lower or movable block. The power ratio is then 3 to 1, and the pull is in the opposite direction to the load, which is usually a great advantage.

By increasing the number of sheaves in the blocks any required ratio of power may be obtained. A certain proportion of the power is lost in overcoming the friction in the block and the resistance of the rope to bending.



XXXI. Dragging log up steep slope with block and tackle. As the elephant descends, the log is raised to the top of the slope.

Care of tackle. In using tackle special precautions are necessary to prevent it from twisting, especially where blocks with several sheaves are used. A short wooden lever called an 'anti-twister' is usually lashed to the movable block, and a thin rope is attached to the end of this lever to control it.

When using tackle for lifting and loading logs or other heavy weights, steadying ropes should always be attached to the load to keep it from swinging.

Care must be taken to see that the tackles used are in good condition and the blocks well lubricated. Before using the tackle it must be seen that the standing end of the fall has been made secure and that the rope is free from kinks, and also that the men are in a position where they will not be injured in case of an accident. The blocks should be kept clean and free from grit, and tackles should always be carried and never dragged along the ground.

Derricks and the use of spars. A standing derrick is a single upright spar which can be used for raising and swinging a weight into any position within its reach, which is about one-third of its height. The spar is set up with four guy-ropes at right angles to one another, secured to the head with clove hitches. A block for the tackle is lashed to the head of the spar, and a short wooden crosspiece should be lashed under the block so that the tackle does not come in direct contact with the spar. The anchorages for the guys should be at a distance from the foot of the derrick equal to twice its height. The foot should be let slightly into the ground to prevent it from slipping, and in soft ground a special footing of rock or stone should be prepared.

The safe limit of incline for derricks is 3 in 1, and this regulates the distance at which a weight can be picked up by a derrick. When first erected the incline should not exceed 5 in 1. A derrick used in conjunction with a skidder is shown on plate XXI, and the method of erection of a heavy derrick is shown on plate XXXII.

To raise a derrick the spar is first laid on the ground with the butt nearly over the footing. A foot-rope is secured to the butt, and to an anchorage post on the same side of the footing as the spar and close to it, as shown in plate XXXII. When the four guys have been secured to the head, the spar is gradually lifted as high as possible by hand, being supported after each lift by temporary struts, and is then hauled up by the guy-ropes. Pairs of bamboos tied together near their tops, and crossed to form a fork or *gwa*, are generally used in forest work to assist in raising the derrick, and also to form temporary struts until it is high enough to be hauled up by guy-ropes.

Raising derrick by a lever. If a derrick is too heavy to be lifted by hand to the height at which the guy-ropes can be effectively used, a spar-lever is brought into use, as shown in plate XXXII. The lever is lashed to one of the guys by taking a number of turns with a small rope round the guy-rope and the tip of the lever and ending in a draw-knot. A long loose end is left so that the draw-knot may easily be pulled out later from ground level. The lever must be provided with side guy-ropes to keep it in position. The butt of the lever is placed close alongside the derrick and not far from its butt. The tip of the lever is then raised so that the guy-rope attaching the lever to the derrick is drawn taut. The guy-rope is now immediately above the derrick, and by continuing to haul on this rope the derrick is slowly raised. When the lever is of no further use it will begin to rise off the ground, and should then be released from the guy-rope by pulling the loose end of the lashing.

In the photograph on plate XXXII the lever is shown almost vertical, and the derrick is sufficiently raised to enable it to be hauled up easily by the guy-ropes. The upper rope on the right of the photograph, which appears to be the back guy-rope, is actually the side-guy on the same side of the derrick as the camera.

In forest work a lever-spar is useful when erecting any long and heavy posts, such as the central house-posts for a Forest Rest House, or other buildings.

Sheers or sheerlegs. These consist of two spars with their butts apart on the ground and their tips lashed together and held steady in the air by a fore and back guy. A load lifted by sheers can be swung through between the legs by letting out the fore guy and hauling on the back guy, the fore guy being let out very cautiously when the sheers become nearly vertical. The fore guy may be dispensed with in certain situations, as when loading a boat from a river bank, but in this case the sheers must have a distinct lean outwards. Sheers are simpler to handle than derricks, and lighter spars may be used. They require only two guy-ropes, but they can move a weight in a straight line only.

The illustration shows a pair of sheers being used in bridge construction by Burma Forest Students. Sheers are particularly adapted to bridge work, and large girders can easily be hauled across a stream by sheers erected on the opposite bank.

Erection of sheers. Two spars, about 30 to 35 feet in length, are laid with their butts flush together on the ground, but supported on a crosslog near their tips. A clove hitch is made round one spar about 3 feet from the tip, and the rope is taken loosely six or eight

XXXII. (*a*) Sheerlegs being used in bridge construction in the forest.

(*b*) Raising heavy derrick by means of a lever spar, at Mandalay.

times round both spars above the the clove hitch, without riding. Two 'frapping' turns are taken round the lashing and between the legs, and the end of the rope is then secured to the second spar by two half-hitches just above the lashing. The butts of the spars are then opened out till their distance apart is about one-third of the length of the spars from butt to lashing, and a sling is passed over the fork. With large spars the feet should be separated before lashing the tips together, as otherwise the lashing is drawn too taut.

The logs should be prevented from splaying by tying them together near their feet, and for large spars footings should be prepared. The guys are made fast near the tips of the spars, by clove hitches, in such a way that they will draw the spars together when they are hauled taut. This is done by tying the fore guy to the rear spar and the back guy to the front spar, as shown in plate XXXII.

Sheers are raised in the same way as derricks. Up to 35 feet in length they can be raised by a lever, but heavy sheers are best raised by means of a small derrick placed between the legs. The limit of the working slope of sheers is 3 in 1, the same as for a derrick, and the slope should not exceed 5 in 1 when first erected, to allow for the stretching of the guy-ropes and fastenings.

Size of timber for derricks and sheerlegs. The length of the spars must be sufficient to allow for the length of the slings and for the blocks, in addition to the height that the weight must be lifted. When the fixed and moving blocks are hauled up close together, or 'chock-a-block', the tackle will occupy 4 to 5 feet. The length found most suitable in forest bridge construction is about 32 feet, and the spars should be about 7 to 8 inches in diameter for sheers, and 8 to 10 inches for derricks.

Gyns. A gyn or tripod consists of three spars lashed together at the tips, the butts forming an equilateral triangle on the ground. No guy-ropes are required, but a gyn is intended for a vertical lift only, and is of limited use in forest work.

The three spars are lashed loosely together near their tips, while on the ground, and two of the spars are then crossed until the distance between the butts is equal to half the length of the legs. For large gyns, a tie or ledger is then lashed across near the feet of the first two spars when spread out. The gyn is raised by using the third spar as a 'pry-pole', and two more ledgers are then usually lashed to the feet to hold the third spar in position.

Small gyns or tripods are often used in sinking wells, and a simple tackle is attached for hauling up the excavated material. Gyns with tackle are also sometimes used in loading carts and also for

improvised pile-drivers, as already explained. It is dangerous to use a gyn for swinging a load for any considerable distance, as the gyn is likely to capsize sideways.

3. BLASTING

Blasting is frequently necessary in forest work, for the removal of rock obstructions from floating streams, and from the roadway during road construction, and also in quarrying stone for road metal. The procedure is the same in all cases, and the blasting is carried out by means of small charges of explosive placed in holes of small diameter, called bore-holes.

Method of boring. Bore-holes are usually made with steel jumping bars, 5 feet 6 inches to 7 feet long, which are used by being lifted up by hand and dropped repeatedly in the same place. A light twist is given to the jumping bar each time it is raised to avoid the bar jamming in the bore-hole, and, in most kinds of rock, water is poured into the hole to assist the boring. The bars have chisel-shaped points at both ends, slightly wider than the diameter of the bar, which is usually one inch, and a hole is made $1\frac{1}{4}$ to $1\frac{1}{2}$ inches wide. Jumping bars are only suitable for drilling holes which are vertical or nearly vertical, and in other cases a 'Boring bar' is used.

Boring bars are made of octagonal steel, about 3 feet 6 inches to 4 feet long, and have a chisel point at one end only. One man holds the bar in position, twisting it slightly after each blow, while a second man strikes the upper end with a hammer.

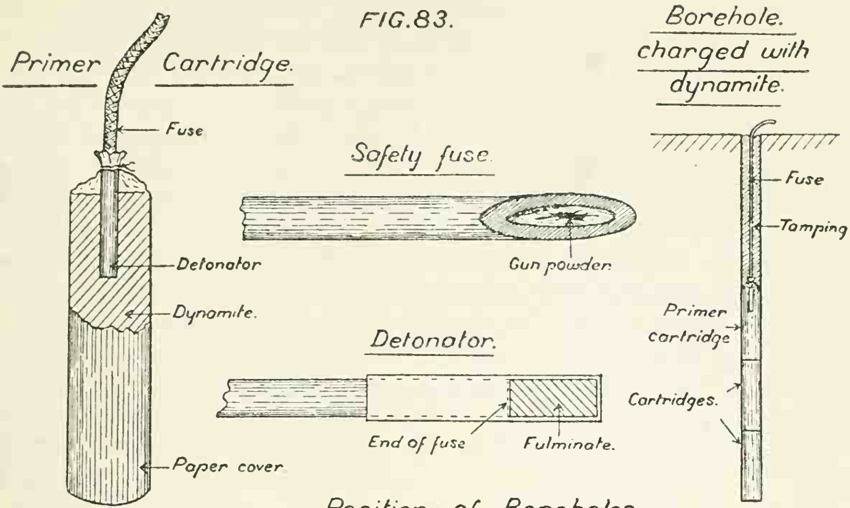
The powdered rock formed in the hole is usually removed by a brush, made by beating the end of a fibrous green stick, cane, or bamboo, to which the powder clings and is easily withdrawn. Specially shaped metal 'spoons' are also used for removal of the dust, but the locally-made brush answers the purpose equally well.

Position of bore-holes. When boulders are to be blasted the depth and position of the hole should be such that the charge lies as near as possible to the centre of the boulder.

If rock has to be blasted from a steep cliff face it is always better to work down from the top, if possible, as this makes the boring easier; and the best effect from a charge is obtained where there are at least two exposed surfaces (see fig. 84).

The depth and the distance of the holes from the vertical face will vary greatly with the nature of the rock and with the number of cracks or fissures it contains, but in average rock, holes 3 to 5 feet, deep 6 feet apart, and 3 feet back from the vertical face, will be found generally suitable. Deeper holes are used in large quarries and in

FIG. 83.



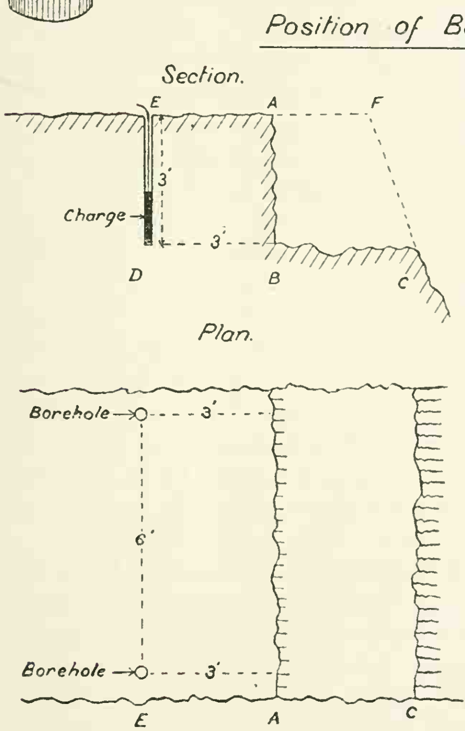
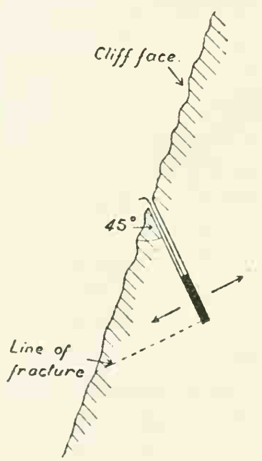


FIG. 84.

FIG. 85.



mining, but require special boring drills. Shallow holes mean a waste of explosives. In fig. 84 the part *AFBC* has been blasted away and the part *EADB* will be removed by the next explosion.

If it is necessary to cut a road along the face of a high vertical cliff, it may sometimes be impossible to work from the top, and in that case the first row of bore-holes should not make a greater angle than 45 degrees with the face of the rock, as shown in fig. 85, as the direction of the maximum effect of a charge is at right angles to the bore-hole. When the first row of bore-holes have been blasted by these 'breaking-in' shots, subsequent bore-holes can usually be made, more or less vertically, by working down from the newly cut face.

Use of dynamite. Dynamite is the explosive most commonly used in forest work. It is stored in special 'magazines' and can be obtained only by Government permit or licence, which covers the right to purchase and use it for one year. After the work is finished any remainder should be returned, unless a magazine for storage is available locally. Explosives should never be stored in an ordinary dwelling-house. When issues of explosives are made to contractors, only a few cartridges should be given at a time, or some are certain to be stolen and used for illegitimate purposes. A register showing all receipts and issues should be maintained and frequently checked.

Dynamite is sold in 50 lb. cases, and there are 10 packets in a case. A packet contains about 36 cartridges, $\frac{7}{8}$ or 1 inch in diamter and $3\frac{1}{2}$ inches long, and weighing from 2 to $2\frac{1}{3}$ oz. each. The boxes should not be opened until the dynamite is required for use.

Dynamite is not dangerous if properly handled, and will stand ordinary shocks, such as dropping it on the ground, without explosion, but boxes containing dynamite should always be handled carefully. It should not be exposed for any length of time to the heat of the sun or placed near a fire, and in hot weather dynamite should not be handled with bare hands more than is necessary, as the skin absorbs a poison from the dynamite which often causes severe headache and sickness.

Detonators. Dynamite cartridges are always exploded by means of detonators, and these detonators are dangerous and must be kept apart from the dynamite, both in the store-room and during transit. A detonator is a thin copper tube, about $1\frac{1}{4}$ inches long, closed at one end, and charged with a small quantity of fulminate of mercury (see fig. 83). Detonators are packed in tin boxes lined with felt and containing sawdust. It is important to see that no sawdust is left in the detonator tube before use.

Detonators must always be handled very carefully. The small

charge in one detonator is sufficiently powerful to blow off several fingers if it explodes in the hand, and it is very sensitive to abrasion, shock, or heat. Detonators must not be carried loose in the clothes pockets. No. 3 detonators are sufficient for dynamite, but No. 6 or No. 8 are necessary for gelignite or blasting gelatine.

Fuse. The fuse used for blasting is known as 'safety fuse' and burns at the rate of 2 feet per minute. It contains a small column of gunpowder in the centre, and has an outside covering of waterproof tape, usually black in colour. Safety fuse is supplied in sealed tins containing 8 or 24 fathoms. The rate of burning should always be tested before using a new roll of fuse, especially if it has been kept in stock for some time.

Preparation of primer cartridge (see fig. 83). The primer cartridge contains the detonator and fuse. First cut off the proper length of fuse so that it is about 3 to 6 inches longer than the depth of the bore-hole. The fuse should be cut with a sharp knife, clean, and straight across. One end is then inserted into the detonator so that it is in close contact with the fulminate, but the detonator should not be screwed or twisted on to the fuse. Pinch the *open end* of the detonator firmly on to the fuse with pincers, but be careful not to squeeze the end containing the fulminate. Do not let the ends of the fuse get damp, and for work under water, or, if water tamping is used, make the joint between the detonator and fuse watertight with wax or rubber tape.

Next take a dynamite cartridge and open the paper at one end, and after making a hole in the cartridge with a small stick or lead pencil, push the detonator into the hole, leaving one-third of the detonator tube projecting outside the dynamite, as in fig. 83. Then tie the cartridge paper firmly round the end of the fuse and detonator with string, and the primer is ready to lower into the bore-hole, as explained below.

Charging the bore-hole. After the bore-hole has been cleaned out the dynamite cartridges are lowered one by one and pressed into the hole. The lower and tighter the charge is in the hole the greater the effect of the explosion, and the wrapping paper should be cut open on one side, but not removed, to allow the dynamite to fit the hole more closely when squeezed from the top, with a wooden rod. A primer cartridge is now prepared, and lowered or pushed very gently down the bore-hole, so that it is in close contact with the other cartridges, as in fig. 83.

One cartridge may be sufficient for boulders or for a shallow bore-hole, but the number of cartridges necessary can best be found by

actual experiment. Theoretical calculations based on the 'line of least resistance', or LLR, are of little use in actual practice to the ordinary forest ranger. Two, three, or four cartridges are used in a 3-foot bore-hole in solid rock, depending on the position of the borehole and the quality, condition, and texture of the rock. When measuring the effects of experimental charges at various distances from a free face it should be noted that, as we are dealing with volume, the charges must be proportionate to the *cube* of the distance. For example, if 4 oz. are necessary at 2 feet from the face, then at 3 feet we shall require $\frac{3^3}{2^3} \times 4 = 13\frac{1}{2}$ oz.

Tamping. The power of an explosive is greatly increased if the bore-hole is plugged with rammed clay or earth, and this is called 'tamping'. At least a third of the depth of the bore-hole should be plugged with tamping material, and it is usual to fill the hole to the top. Good tamping is specially necessary if gunpowder is used. Moist clay, or soil from an ant-heap, makes the best tamping material, and it is important to see that the material used does not contain any sharp stones. First pour in a little sand over the primer cartridge, and then add a little moist clay. Press this down gently with a wooden rod, and then put down several inches more of damp clay and press down firmly. In the case of dynamite it is not necessary to ram the tamping down so firmly as for gunpowder, and water or sand is often used instead of clay.

Firing. The end of the fuse should be cut about $\frac{1}{4}$ inch deep down the middle and thus split into two pieces which are spread apart. The gunpowder in the fuse is then exposed and can be lit with a match or, more easily, with a cigarette or cheroot, A simpler method is to cut the fuse at a slant with a sharp knife, and light at once. Several charges are usually prepared and fired at the same time.

The charges may also be fired electrically by means of a dynamo exploder and special detonators, but this method is very rarely used in forest work.

Misfires. If a charge fails to explode, do not go near the hole for at least twenty minutes, and do not attempt to remove the tamping or charge, or touch the misfired hole in any way. Bore a second hole at least one foot away from, and a little deeper than, the misfired hole, and in such a direction as will keep the boring-tool well clear of it. Then charge and fire the new hole, and afterwards search the debris thoroughly for unfired detonators and cartridges.

Every precaution should be taken to avoid misfires, as they waste time and are always dangerous. Make sure that your fuse is well

alight before you leave it. There is always plenty of time to get under cover. If explosives are being used near a road, men must be posted to warn people away while blasting is actually in progress.

Gelignite and blasting gelatine. Blasting gelatine is used for blasting very hard rock, especially under water, and is about 50 per cent. stronger than dynamite. It is made up in similar cartridges to dynamite, and is treated in the same way. As already mentioned, a specially strong detonator, either No. 6 or No. 8, is required to explode blasting gelatine. Gelignite is a nitro-glycerine mixture halfway between dynamite and blasting gelatine, and the cartridges are prepared for explosion in the same way, but are more plastic than dynamite. It is specially useful for blasting under water, and is sometimes merely placed on the surface of the rock and fired, but this method is very wasteful.

Gunpowder is not an efficient explosive for rock-blasting, as it is only about one-quarter the strength of No. 1 dynamite and therefore requires four times the amount of labour in preparing bore-holes. It is useful for quarrying stone where it is not desired to break and shatter the stone into small pieces, such as result from the use of dynamite or gelignite.

Gunpowder requires very firm tamping. If used under water it must be placed in watertight bags. A detonator is not used for gunpowder, and the end of the fuse is simply inserted into the charge. Gunpowder is bulky and more difficult to handle than dynamite, and special precautions must be taken against sparks or fire reaching the powder. It is used in boreholes in the same way as dynamite, and the same general rules and precautions should be followed.

Clearing tree-stumps. Large tree-stumps may be quickly and cheaply cleared from road-cuttings by cracking or splitting them with explosives, which will enable them to be removed or burnt afterwards by fire. The best method is to bore one or more holes with an auger into the stump at an angle of 45°, commencing just above ground-level, not quite deep enough to reach the centre of the stump. Charge the hole with half a cartridge of dynamite and fire in the usual way. Explosives should only be used for very big stumps which cannot be removed by a monkey-winch.

Removal of soft rocks. Sandstone and limestone can frequently be broken up and removed by picks, to avoid the use of explosives, and it should be remembered that these rocks harden on exposure, and so are often softer beneath and more easily excavated than appears from a casual inspection of the outcrop. High explosives such as dynamite

are wasted on soft rock, and large boulders can frequently be cracked by burning with fire and pouring cold water on them while the rock is very hot.

4. PACK-GEAR FOR BAGGAGE ELEPHANTS

The dragging gear used in timber extraction has been dealt with in Chapter X, and here we have only to consider the pack-gear used for the transport of kit and stores by elephants. Sore backs, abscesses, and galls are caused by badly fitted gear or careless loading, and can usually be avoided if proper care is taken.

The chief point to note in all pack-gear and saddlery is that the spine of the animal must be free from pressure. The load must always be carried on the muscles above the upper part of the ribs on each side of the backbone, and must not be too far forward, or it will interfere with the play of the shoulder. This applies to elephants as well as to pack-mules and bullocks.

The gear in general use by the Forest Department for baggage elephants consists mainly of two pads, called the *guddela* and the *guddee*. The *guddela* is a thick flexible pad covering the whole of the back of the elephant, from the nape of the neck to the croup, and hangs half-way down the sides. The size of the pad depends upon the height of the elephant, but for an elephant of 7 feet 6 inches to 8 feet in height it should be about 5 feet 6 inches by 4 feet. The *guddee* consists of two pads of stout material, such as sailcloth or jute, stuffed tightly with reeds, and connected together at both ends, leaving an open gap down the middle, so that one pad lies on each side of the elephant's backbone and protects it from pressure. The stuffing must be packed tightly and evenly, and not in lumps, and the guddee should be fairly hard and rigid in order to distribute the pressure of the load evenly. The average size of a guddee when empty is 5 feet 3 inches by 4 feet 9 inches, which is reduced to about 5 feet by 4 feet when stuffed. If guddees and guddelas are properly used they should last for about three years. When on the march it should be seen that the guddee has not slipped either forward or backward off the guddela, as this is a frequent cause of a sore back.

Girths. The best form of girth is a woven band of strong rope about $4\frac{1}{2}$ inches wide, with leather-bound edges. At each end of the girth is fixed an iron dee and a small hook. A double rope is passed over the top of the guddee with a small pulley-block and short chain attached to each end, and of such a length that the dee-hooks of the girth can be hooked when tight to the bottom links of the chains on both sides. Further tightening is carried out by small ropes tied to

the girth-dees, which are threaded through the pulleys and pulled downwards, so that further links of the chains can be taken up by the dee-hooks of the girth on each side of the elephant.

It is important to see that the girths are tightened up during the march, as however tight the girth may be pulled when loading it always slackens later, and the swaying of the load may cause a sore back. The girth must be kept well lubricated with pigs' fat to prevent galling the animal. This is especially important with new gear.

The *crupper* is a bent piece of iron piping which allows the crupper-rope to slide easily through and prevents chafing the animal under the tail. The crupper-rope is tied to two ropes which pass along the whole length of the guddee, and are attached to it on the upper side.

Neck and baggage-ropes. The neck-rope is fastened to the same ropes as the crupper-rope, but in front of the guddee, and is bound by leather to prevent chafing. Short baggage-ropes are also attached and hang down on each side. A separate rope of smaller thickness is provided to tie the tarpaulin cover over the load.

Care of gear. Guddees and guddelas should be kept as dry as possible, and they should never be left lying flat on damp or wet ground but should be leant against a tree, or, during a long halt, should be hung up on poles to protect them from white ants and from rot. They should be kept under cover during the rains, and in fine weather the underside of the guddelas should be exposed to the sun to dry after use.

Loading. It is of great importance that the loads on each side of the elephant should be of equal weight, and it is even better to add unnecessary articles than to leave the sides unbalanced. No part of the load should touch the animal either in front or behind the guddee, and mahouts must be prevented from dropping fetters or chains in the space between the guddees over the elephant's spine, as this is a frequent cause of trouble.

Loaded animals should never be kept standing but should either be moved or off-loaded at once. Four boxes, each about 2 feet by 15 inches by 13 inches, are the most suitable for elephant loads, and these boxes can also be used for mule packs. The maximum load for a good female baggage elephant is 700 lb., exclusive of gear. This should be reduced to 400 lb. in very hilly country.

Rules for the working of elephants. The following rules, which are taken from Forest Departmental Instructions, must be observed when using baggage elephants:

'Elephants must not be worked in the heat of the day and not later than 10.30 a.m. after April 1st, but they should not be worked

in the very early morning hours if avoidable, as this is the time they usually sleep or feed. They should not be marched for more than five hours on any one day, or for more than four hours a day on an average. Loaded elephants should not be marched for more than five consecutive days, or, generally, for more than ten days out of fifteen. At the end of march in the hot weather, after unloading, the elephants should be allowed to cool down before their pads are removed. Their backs should then be massaged by the mahouts. After a hard day's work it is a good practice to rub a little salt into the elephant's back to harden it, but this is rarely done except in the case of elephants used for dragging. The elephants should not be turned loose in camp, but should be marched off to a suitable grazing ground before being fettered. If tied up for the night sufficient fodder must be cut and given to the elephants before dark, but tying up should be avoided unless absolutely necessary. Elephants should not be brought near a railway line, and should not be grazed in areas frequented by cattle, if this can be avoided. During the hot weather a ration of fresh tamarind and salt should be given at frequent intervals, and if an elephant has been overworked it should be given special rations of paddy or sugar-cane.'

All Government elephants are branded on the buttocks with a special Forest Department stencil, 9 inches high by 6 inches broad, and the brand must be renewed regularly.

5. FENCING

Posts and rails. Wooden posts and rails are easy to erect and are used for many purposes, such as for fencing round forest buildings and for protective railing along roadsides. Posts are placed about 8 feet apart and support two or more rows of rails. The posts should be from sound heartwood of a durable species of timber, and before being erected the timber should be thoroughly dry and the part entering the ground must be charred or tarred. The tops of the posts should be pointed and tarred to throw off rainwater and to prevent decay. Common sizes of posts are 5×5 inches or 6×4 inches, and about $5\frac{1}{2}$ to 6 feet long, sunk at least $2\frac{1}{2}$ feet into the ground. Roughly squared or split posts are the cheapest and most suitable for forest work. Where available, very strong and durable posts can be made from old or rejected railway sleepers.

For roadside fencing the posts should be supported by struts on the outer side from the road. These struts are usually fixed to alternate posts or to every third post. A level footing about $2\frac{1}{2}$ feet long is often spiked across the base of the strutted posts before they are

erected, and this supports the lower ends of the struts which are spiked to the posts and to the footings.

The rails are usually 2×4 inches, or 3×2 inches, and, for protective fencing round the compound of a Forest Rest House, three lines of rails, placed about 1 foot 3 inches apart, should be used. For a permanent fence the rails should be supported in mortises cut through the posts, but a cheaper method is to spike the rails into notches cut the same depth as the thickness of the rails, as already explained for bridge hand-railing. The length of the rails must be such that the ends of the rails coincide with the posts, and this ensures that the joints are all supported.

A very cheap and simple form of fence may be made from a single row of round poles supported on the tops of forked posts about 3 feet high and 6 to 9 inches in diameter, placed 10 to 12 feet apart. This fence will keep out village cattle, and is commonly used where sawn timber is not available. It is less than half the cost of an ordinary post and rail fence.

Bamboo fences. Very strong fences can be made of split or squared timber posts, with split bamboo interlaced between rails. The posts are placed about 8 feet apart, and the split bamboo may be interlaced between four horizontal bamboo-rails or between four stretched wires. These fences can be made very formidable by the addition of short pieces of split bamboo, sharpened at both ends, and interwoven so that both points protrude for about 2 feet from the fence in all directions. Village fences are usually of this type.

Wire fences. Wire fences are more durable than wooden or bamboo fences, and are gradually taking the place of bamboo fences in many districts. They are easy to construct, and are specially suitable for places where there are large areas to be enclosed, and are often cheaper than post and rail fencing.

A good cattle-proof fence, for surrounding a nursery, can be made of four lines of wire, the three lower ones being plain and the top one barbed. The plain wire for the lower strands should be about No. 6 gauge, solid and galvanized. A suitable type of barbed wire for the top line is 14 gauge, 2 ply, 4 point, with galvanized barbs 3 inches apart.

Strong straining posts are necessary for wire fences, at the ends and at each change of direction. All straining posts must be strutted near their tops, by long struts placed in the direction of the line of the fence. The wires are attached to iron straining bolts which pass through the straining posts and are fitted with an eye at one end and a screw thread about 8 to 10 inches long at the other end, to receive

a nut and washer. After the straining bolts are in position the wire is attached to the ends and is drawn taut by tightening the nuts. In erecting a wire fence the bottom wires should always be tightened first. There are various forms of iron straining-brackets or 'winders' for wire fencing, but simple straining bolts are the most suitable for forest work. Smaller intermediate posts are placed between the straining posts, and the wires are fastened to them by galvanized staples.

Barbed wire is sold in reels of either ½ cwt. or 1 cwt. It is wound round a hollow core through which a stick can be passed, and by holding the ends of the stick and walking along the line of the fence the wire is uncoiled evenly and can be kept taut. Barbed wire should not be used for fences round Rest Houses or other forest buildings, and there are Government orders forbidding its use except under certain conditions, and in some districts local by-laws forbid the use of barbed wire along roadsides.

For protecting a forest nursery against small animals such as hares, wire netting must be fastened along the bottom of the fence, the lower edge being pegged down and buried a few inches below the surface of the ground.

Woven wire fences. The wire is purchased ready woven, and can be obtained with square meshes of various sizes, and with various gauges of wire. A good woven fence to keep out all animals has large meshes near the top and smaller meshes below. The initial cost of a woven wire fence is much greater than for plain wire, but it gives better protection and is more durable. 'Stretchers' are generally used for woven wire, consisting of a pair of wooden clamps which are bolted together through the meshes, but after it has been stretched tight the wire is simply fastened to the posts by staples. The fence can be easily removed and used again elsewhere. For permanent fencing in head-quarters a woven wire fence is often used with reinforced concrete posts, and in Upper Burma this form of fence costs at present about Rs. 60 per 100 running feet, complete with posts, which is about double the cost of an ordinary post-and-rail or woven bamboo fence.

Hedges and ditches. Live hedges of bamboo or thorny shrub are often used instead of fences, and where the soil is suitable, hedges should be planted round forest buildings to save the maintenance of fences. Hedges need the protection of a temporary fence until they are well established, and then ditches dug along the outer side of the hedges will protect them from damage. The only protection practicable against wild elephants is a deep ditch 6 feet wide with perpendicular sides.

6. BOUNDARY POSTS AND PILLARS

A standard type design for boundary posts and pillars has been adopted by the Forest Department in Burma, and all posts should be made according to the specifications, which are given below for reference. Stone and masonry pillars are not used in Burma owing to the shortage of stone and the high cost of masonry.

Boundary posts must be of durable timber, such as teak or *pyinkado*, and must consist entirely of heartwood. Green teak should not be used if other durable timber is available. The posts must be at least 8 inches in diameter after removal of sapwood, and from $7\frac{1}{2}$ to 9 feet long, and roughly pointed at the top. Flat faces must be cut near the top of the post wide enough to receive the necessary numbers, which are demarcated with short broad-headed 'clout' nails. On Forest Reserve boundaries the numbers will of course face outwards, but for inter-compartment boundaries the numbers are placed on the same side of the post as the compartment.

Stone cairns (see fig. 82). If stone is available, stone cairns should be erected round the posts for protection. The base for the cairn should be excavated with an inward slope towards the centre as shown, as this tends to keep the stones in the cairn packed together. The largest stones should be placed at the bottom, and the diameter at the base must not be less than 6 feet.

Earth-mounds. If stone is not available, earth-mounds must be made. The mounds must be 4 feet high in the centre and 8 feet in diameter. The earth is supported by split bamboo interlaced to form a mat revetment. The revetment is made 2 feet 6 inches high and 8 feet in diameter at the base, and the sides must slope inwards to the post so that the diameter of the revetment at the top is not more than 7 feet (see fig. 81). The earth for the mound must be dug from trenches 3 feet wide by 1 foot deep along the exact boundary line on each side of the post, but the trenches must not be commenced within 5 feet of the base of the mound.

The earth should be well rammed, and given an outward slope at the top to throw off rainwater. About one foot of the post should project above the mound, and, in places where damage is to be expected from wild elephants, barbed wire should be wound round the top of the post or it may be studded with projecting nails.

In the Shan States, and in other places where neither stone nor bamboo is available, the revetment of the earth-mound is done with a cribwork of poles, which are notched together, as shown in the drawing in fig. 58 for pile cribwork. The frame is made about 6 feet square and 2 feet 6 inches high, and is filled with rammed earth.

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